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Rudimentary and Elementary

TREATISE ON

STEAM AND LOCOMOTION;

BY JOHN SEWELL, L.E.

VOL. II.

With Illustrations.

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ELEMENTARY TREATISE

ON

STEAM AND LOCOMOTION;

BASED ON THE PRINCIPLE OF

CONNECTING SCIENCE WITH PRACTICE,
IN A POPULAR FORM.

With Illustrations.

BY

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A TREATISE

ON

STEAM AND LOCOMOTION.

PART II.

CHAPTER I.

PRESSURE OF AIR AND ELASTIC FLUIDS.

UNTIL near the middle of the seventeenth century it was not even suspected that the air possessed either weight or elastic force. Pumps, being an earlier invention of Ctesibus, had come into general use for raising water, and practical men had noted the fact that water rose far above its natural level in the pump tube, when the working valve, or bucket, had withdrawn the air from that part of the tube. Philosophers explained this as a proof of nature's abhorrence of a vacuum, which caused the water to fill the vacuum in the pump tube, and in fixing them this was taken advantage of by placing the working valves where most convenient. However, a pump having been erected at Florence for the Duke of Tuscany, it failed to raise any water, and its failure was a very unexpected result. It was then ascertained that the water was above 33 feet distant from the pump valve, and only rose to about that height, but not within the action of the pump, hence the cause of the failure was apparent, but not so the limit thus assigned to Nature's abhorrence of a vacuum. Galileo was consulted, but was unable to give any valid reason for this limit at the time. Reflection, however, led him to conclude that the air had weight, and that the weight pressing on the

water caused it to rise. Following out this reasoning, his pupil Torricelli had the honour to construct the first barometer, and to determine by experiment the relative weight and pressure of air.

As barometers are applied to measure the pressure of steam as well as that of air, a description of them will be instructive.

Fig. 30.

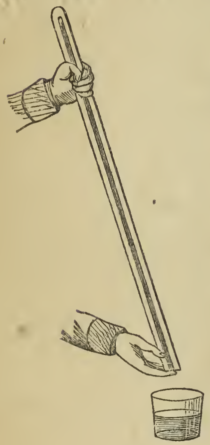


Fig. 31.

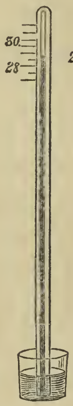


Fig. 32.

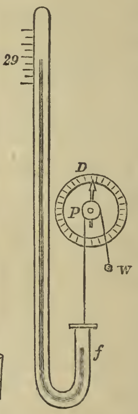


Fig. No. 30 or 31 is a glass tube about 36 inches long, closed at one end, which Torricelli filled with mercury, carefully excluding the air. Then applying his finger to the open end, he inverted the tube with its open end in a cup containing both water and mercury. He then withdrew his finger while the tube end was immersed amongst the mercury, when it flowed out until it became stationary at a height of about thirty inches. When the end of the tube was raised out of the mercury, and open to the water, the mercury flowed out, whilst the water rushed in to the top of the tube, showing that it would have risen still higher, had the tube been longer. These simple yet beautifully important experiments clearly demonstrated that the pressure of the air was equal to the pressure of a column of mercury thirty inches high, or to a column of water of an equal pressure.

The specific weight of mercury varies according to its purity and temperature, but in ordinary circumstances it is about 13·6 times heavier than water, hence the height of a column of

water equal to the weight of a column of mercury 30 inches high, would be 30 × 13·6 ÷ 12 in. = 34 feet, which water would rise in a perfect vacuum by the pressure of the air on its surface. This, therefore, proved that the water would rise to a height in the pump tube more or less near to 34 feet, as the vacuum was more or less perfect, but beyond 34 feet the pressure of the air would fail to raise the water, thereby solving the pump problem in the most satisfactory manner. Since a cubic foot of water is nearly and usually taken as 1000 ounces avoirdupois, a cubic foot of mercury would be 1000 × 13·6 = 13,600 ounces, and one inch of mercury would be 13,600 ÷ 1728 = 7·87 ounces, therefore 30 × 7·87 ÷ 16 ounces = 14·75 lbs. as the elastic force of the air at the level of the sea. In round numbers it is usual to consider the pressure of the air as equal to 15 lbs. on each square inch, which is called the pressure of one atmosphere, 30 lbs. being that of two atmospheres, 45 lbs. that of three atmospheres, and so on with each additional 15 lbs. It will illustrate the pressure of elastic fluids in every direction, when it is stated that the pressure of air on the body of an average-sized man amounts to about 15 tons, which of course would instantly crush him to the earth, were it not counteracted by its equality of pressure in every direction, upwards, sidewards, downwards, internally and externally. Its weight is about 820 times lighter than water, (or ·00122,) as determined by M. Arago. The elastic force of air on a square foot of surface would amount to 144 × 14·75 lbs. = 2124 lbs., but the weight of 144 cubic inches would only be ·00669 lbs. or nearly 31·72 times less weight than pressure. This greater pressure is due to the superincumbent column of air estimated by some as from 45 to 50 miles high, but by others as not even so high as 40 miles.

Air has, therefore, both weight and force pressing in every direction, in the ratio of 2124 lbs. per square foot of surface, yet in it we live, move and breathe, as if it had neither weight nor

H 2

force. Many attempts have been made to bring the elastic force of the atmosphere into mechanical use like steam. The Croydon and South Devon Atmospheric Railways now abandoned, and Prosser's compressed air engine now in the great exhibition, are recent instances of these efforts, but as yet they have been unable to compete with steam in portability and economy.

To the feelings the changing pressure of the air seems reversed to what it really is, for on a fine dry day the air is heaviest, causing the mercury to rise, and on or before a wet day it is lightest, allowing the mercury to flow out of the tube or fall. Yet on a fine day the feelings are buoyant, and on a wet day depressed. This is easily accounted for.

Natural steam is only about one half or five eighths the weight of an equal volume of air, hence when the air becomes saturated with natural steam it is of course lighter, and in an equal volume contains less oxygen. When the natural steam has fallen in the form of rain or snow, the air becomes heavier from its containing more oxygen in an equal volume, for oxygen is 1·11 times heavier than the mixture of $\frac{4}{5}$ nitrogen and $\frac{1}{5}$ oxygen, which constitutes the atmosphere. The more oxygen inhaled the more buoyant and elastic are the feelings, hence as the barometer tells by rising, so the lungs also by expanding, that more oxygen is present; and as the barometer indicates by falling that steam has displaced a portion of the oxygen, so likewise does the collapsion of the lungs truly indicate the absence of the life-supporting oxygen. Whilst, therefore, the barometer weighs the exact pressure of the air, the lungs also tell us its life-supporting power with much fidelity.

Fig. No. 32 is the modern form of barometer for halls, where the float is suspended by a fine line over the small pulley *p*, and balanced by a weight *w;* and as the pulley is moved by the action of the float *f*, the indications by the index *i* are read off on a large dial, D.

As we ascend upwards the pressure of the air diminishes, and by this means the barometer is employed to measure the heights of mountains and other elevated places with considerable accuracy, by the fall of the mercury. Pascal first applied it to this purpose; but as the pressure of the air diminishes by increase of temperature, as well as by increase of height, and its density increases by cold, it requires a scale graduated accordingly. For example, a decrease of 1° of temperature increases the density or pressure of the air ·0033 inches of mercury between the limits of 32° and 52°; but from 32° down to zero the mercury falls ·0034 for each difference of 1° of temperature. At an elevation of 500 feet the mercury falls half an inch; but at 31 times 500 ft. high, it only falls 28 half inches, and at 41 times 500 ft. high only 36 half inches.

The following rule gives the heights of places nearly :—

Multiply the difference of the logarithms of the respective barometric heights by 6000 for the height above the level of the sea in feet.

Ex. Required the elevation of a hill at whose base the height of the mercury was 30 inches, and at the top 28 inches,

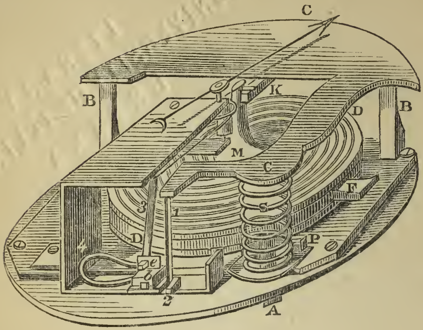
log. 30 = 477121
log. 28 = 447158

Difference = 029963 × 6000 = 1797·78 feet as the height required.

To obtain a more portable and sensitive barometer for such measurements than the mercurial one, a vacuum barometer of ingenious yet comparatively complicated construction has been brought to considerable perfection in France, since M. Conte first introduced it. As now improved by Mr. Dent, of London, it is a portable, and as it may be an agreeable companion to railway travellers for determining the comparative elevation of the countries or railways that they travel over, we annex a brief description of its principle of action.

The same letters apply to all the figures.

Dent's Aneroid Barometer.—Fig. 33.



In Fig. No. 33, D D is the vacuum vase. M, the socket for distending it. C C is a lever, to one end of which is attached the vertical rod, 1, which connects it with the levers, 2, 3. These levers are connected by a bowpiece, 4, and the whole are regulated for the index to move over a space corresponding to the scale of a mercurial barometer. The end of lever 3 is connected to the axes, on which the hand or index is fixed by a piece of fine watch chain. A spiral spring regulates the hand, and the force of the levers in obedience to the indication of the vacuum vase D D, as distended Fig. No. 34, and compressed, Fig. No. 35, by the weight of the atmosphere.

Fig. 34.

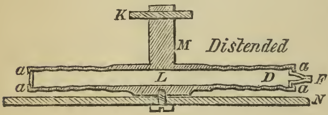
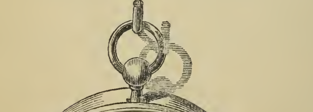


Fig. 35.



Front Elevation.—Fig. 36.

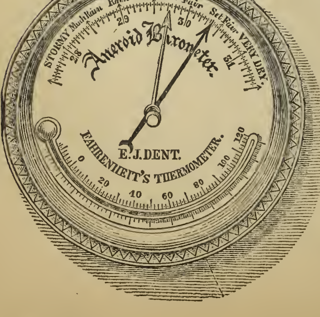


Fig. No. 36, exhibits a front view of this ingenious instrument, and indication hand. W, the index of comparison, to be set exactly over the hand *b*, at the commencement of any experiment. The movement of

the hand O to either the right or the left will then indicate the increase or decrease of the atmospheric pressure.

Diagram showing Principle of Action.—Fig. 37.

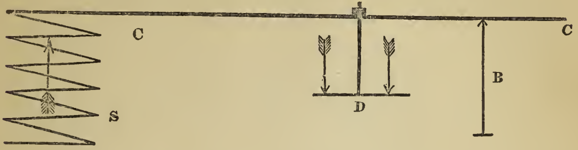


Fig. No. 37, will explain the principle of action. C C is a lever of the second order, similar to a locomotive safety-valve lever, which has its fulcrum at B and its force measured by the spiral spring S. The vacuum vase is attached to the lever C C at D, one-seventh of the distance between B and S. It is 2½ inches diameter, having about 72 lbs. pressure on its area, whose action on the lever C at D, as represented by the arrows, is 6 times increased on the spring S, the lever being as 6 to 1, or 7 parts in all. This it is obvious renders the least variation of pressure quite sensible by the spring when the friction of the parts is reduced to a minimum. In Dent's the motion of the index-hand one-tenth of an inch indicates an alteration of either 85 feet higher or lower, as the case may be. The action of a barometer is therefore regulated by the weight of the air, which is heaviest during serene settled or frosty weather, or when contrary easterly or northerly winds blow it towards any locality. It is lightest when saturated with steam to the rainy point, or when contrary winds blow it away from any locality. In northerly climates the variation is greatest, and least within the tropics.

Several lengthened trials against the best mercurial barometers indicate that the vacuum barometer may be relied on for all ordinary purposes; and the following table will supply the means of ascertaining the comparative gradients of a railway by one of them.

Table No. 34.

BAROMETRIC TABLE.*

Barometric Height.	Atmospheric Height.	Proportional 1000th parts to be added as required.	Barometric Height.	Atmospheric Height.	Proportional '100th parts to be added as required.	Barometric Height.	Atmospheric Height.	Proportional 1000th parts to be added as required.
In. Mer.	Feet.		In. Mer.	Feet.		In. Mer.	Feet.	
28·00	27425·3	+	28·30	27703·7	+	28·60	27979·2	+
1	27434·6	0·9	1	27712·9	0·9	1	27988·3	0·9
2	27444·0	1·9	2	27722·2	1·8	2	27997·5	1·8
3	27453·3	2·8	3	27731·4	2·8	3	28006·6	2·7
4	27462·6	3·7	4	27740·6	3·7	4	28015·7	3·7
5	27471·9	4·7	5	27749·8	4·6	5	28024·8	4·6
6	27481·3	5·6	6	27759·1	5·5	6	28034·0	5·5
7	27490·6	6·5	7	27768·3	6·5	7	28043·1	6·4
8	27499·9	7·5	8	27777·5	7·4	8	28052·2	7·3
9	27509·2	8·4	9	27786·7	8·3	9	28061·3	8·2
28·10	27518·4	+	28·40	27795·8	+	28·70	28070·5	+
1	27527·7	0·9	1	27805·0	0·9	1	28079·6	0·9
2	27537·0	1·9	2	27814·2	1·8	2	28088·7	1·8
3	27546·3	2·8	3	27823·4	2·8	3	28097·8	2·7
4	27555·6	3·7	4	27832·6	3·7	4	28106·9	3·6
5	27564·9	4·6	5	27841·8	4·6	5	28115·9	4·5
6	27574·2	5·6	6	27851·0	5·5	6	28125·0	5·5
7	27583·5	6·5	7	27860·2	6·4	7	28134·1	6·4
8	27592·7	7·4	8	27869·3	7·4	8	28143·2	7·3
9	27602·0	8·4	9	27878·5	8·3	9	28152·2	8·2
28·20	27611·3	+	28·50	27887·7	+	28·80	28161·3	+
1	27620·6	0·9	1	27896·9	0·9	1	28170·4	0·9
2	27629·8	1·9	2	27906·0	1·8	2	28179·4	1·8
3	27639·1	2·8	3	27915·2	2·7	3	28188·5	2·7
4	27648·3	3·7	4	27924·3	3·7	4	28197·5	3·6
5	27657·6	4·6	5	27933·5	4·6	5	28206·6	4·5
6	27666·8	5·6	6	27942·6	5·5	6	28215·6	5·4
7	27676·1	6·5	7	27951·8	6·4	7	28224·7	6·3
8	27685·3	7·4	8	27960·9	7·3	8	28233·7	7·2
9	27690·6	8·3	9	27970·1	8·2	9	28242·8	7·1

* Being an extract, by permission, from the elaborate table of W. Galbraith, M.A., dedicated to Sir Thomas M. Brisbane, Bart.

Barometric Height.	Atmospheric Height.	Proportional 1000th parts to be added as required.	Barometric Height.	Atmospheric Height.	Proportional 1000th parts to be added as required.	Barometric Height.	Atmospheric Height.	Proportional 1000th parts to be added as required.
In. Mer.	Feet.		In. Mer.	Feet.		In. Mer.	Feet.	
28·90	28251·8	+	29·30	28611·1	+	29·70	28965·2	+
1	28260·8	0·9	1	28620·0	0·9	1	28974·0	0·9
2	28269·9	1·8	2	28628·9	1·8	2	28982·8	1·8
3	28278·9	2·7	3	28637·8	2·7	3	28991·6	2·6
4	28287·9	3·6	4	28646·7	3·6	4	29000·4	3·5
5	28296·9	4·5	5	28655·6	4·5	5	29009·1	4·4
6	28306·0	5·4	6	28664·5	5·3	6	29017·9	5·3
7	28315·0	6·3	7	28673·4	6·2	7	29026·7	6·1
8	28324·0	7·2	8	28682·3	7·1	8	29035·5	7·0
9	28333·0	8·1	9	28691·2	8·0	9	29044·2	7·9
29·00	28342·1	+	29·40	28700·0	+	29·80	29053·1	+
1	28351·1	0·9	1	28708·9	0·9	1	29061·9	0·9
2	28360·1	1·8	2	28717·8	1·8	2	29070·6	1·8
3	28369·1	2·7	3	28726·6	2·7	3	29079·4	2·6
4	28378·1	3·6	4	28735·5	3·6	4	29088·1	3·5
5	28387·1	4·5	5	28744·4	4·4	5	29096·9	4·4
6	28396·1	5·4	6	28753·3	5·3	6	29105·6	5·3
7	28405·0	6·3	7	28762·1	6·2	7	29114·4	6·1
8	28414·0	7·2	8	28771·0	7·1	8	29123·1	7·0
9	28423·0	8·1	9	28779·9	8·0	9	29131·9	7·9
29·10	28432·0	+	29·50	28788·7	+	29·90	29140·6	+
1	28441·0	0·9	1	28797·5	0·9	1	29149·3	0·9
2	28450·0	1·8	2	28806·4	1·8	2	29158·1	1·7
3	28458·9	2·7	3	28815·2	2·7	3	29166·8	2·6
4	28467·9	3·6	4	28824·1	3·5	4	29175·5	3·5
5	28476·9	4·5	5	28832·9	4·4	5	29184·2	4·4
6	28485·8	5·4	6	28841·8	5·3	6	29193·0	5·2
7	28494·8	6·3	7	28850·6	6·2	7	29201·7	6·1
8	28503·8	7·2	8	28859·4	7·1	8	29210·4	7·0
9	28512·7	8·1	9	28868·3	8·0	9	29219·1	7·8
29·20	28521·7	+	29·60	28877·1	+	30·00	29227·8	+
1	28530·6	0·9	1	28885·9	0·9	1	29236·5	0·9
2	28539·6	1·8	2	28894·7	1·8	2	29245·2	1·7
3	28548·5	2·7	3	28903·6	2·7	3	29253·9	2·6
4	28557·5	3·6	4	28912·4	3·5	4	29262·6	3·5
5	28566·4	4·5	5	28921·2	4·4	5	29271·3	4·3
6	28575·4	5·4	6	28930·0	5·3	6	29280·0	5·2
7	28584·3	6·3	7	28938·8	6·2	7	29288·7	6·1
8	28593·2	7·2	8	28947·6	7·1	8	29297·3	7·0
9	28602·2	8·0	9	28956·4	8·0	9	29306·0	7·8

Barometric Height.	Atmospheric Height.	Proportional 1000th parts to be added as required.	Barometric Height.	Atmospheric Height.	Proportional 1000th parts to be added as required.	Barometric Height.	Atmospheric Height.	Proportional 1000th parts to be added as required.
In. Mer.	Feet.		In. Mer.	Feet.		In. Mer.	Feet.	
30·10	29314·7	+	30·40	29573·8	+	30·70	29830·2	+
1	29323·4	0·9	1	29582·4	0·9	1	29838·7	0·9
2	29332·0	1·7	2	29591·0	1·7	2	29847·2	1·7
3	29340·7	2·6	3	29599·6	2·6	3	29855·7	2·5
4	29349·2	3·5	4	29608·2	3·4	4	29864·2	3·4
5	29358·0	4·3	5	29616·7	4·3	5	29872·7	4·3
6	29366·7	5·2	6	29625·3	5·2	6	29881·2	5·1
7	29375·3	6·1	7	29633·9	6·0	7	29889·7	6·0
8	29384·0	6·9	9	29642·5	6·9	8	29898·2	6·8
9	29392·6	7·8	8	29651·0	7·7	9	29906·7	7·7
30·20	29401·3	+	30·50	29659·6	+	30·80	29915·2	+
1	29409·9	0·9	1	29668·1	0·9	1	29923·7	0·8
2	29418·6	1·7	2	29676·7	1·7	2	29932·2	1·7
3	29427·2	2·6	3	29685·2	2·6	3	29940·7	2·5
4	29435·9	3·5	4	29693·8	3·4	4	29949·2	3·4
5	29444·5	4·3	5	29702·3	4·3	5	29957·6	4·2
6	29453·2	5·2	6	29710·9	5·1	6	29966·1	5·1
7	29461·8	6·1	7	29719·4	6·0	7	29974·6	5·9
8	29470·4	6·9	8	29727·9	6·8	8	29983·1	6·8
9	29479·1	7·8	9	29736·5	7·7	9	29991·5	7·6
30·30	29487·7	+	39·60	29745·0	+	30·90	30000·0	+
1	29496·3	0·9	1	29753·5	0·9	1	30008·5	0·8
2	29504·9	1·7	2	29762·1	1·7	2	30016·9	1·7
3	29513·6	2·6	3	29770·6	2·6	3	30025·4	2·5
4	29522·2	3·4	4	29779·1	3·4	4	30033·8	3·4
5	29530·8	4·3	5	29787·6	4·3	5	30042·3	4·2
6	29539·4	5·2	6	29796·2	5·1	6	30050·7	5·1
7	29548·0	6·0	7	29804·7	6·0	7	30059·2	5·9
8	29556·6	6·9	8	29813·2	6·8	8	30067·6	6·8
9	29565·2	7·7	9	29821·7	7·7	9	30076·1	7·6

In this table, the middle column exhibits heights in English feet, corresponding to the height of the barometer, shown in the first column, in inches, tenths, and hundredths; the proportional parts to thousandths are given in the right-hand column.

Example.—It is required to find, in English feet, the difference of level between Dover and Folkstone Railway-stations

by the barometer, Dover indicating 30·125 inches, and Folkstone 30·000. In the table at 30·12 we find 29332·0, and in the column A at 5 we have 4·3; which, added to 29332·0, gives for Dover 29336·3. On referring to the 30·000 inches in the table, by which Folkstone is indicated, we find 29227·8. The one, subtracted from the other, gives the difference in feet between the two stations:—

Dover	. . . .	29336·3
Folkstone	. . .	29227·8
	Feet .	108·5

Folkestone-station, therefore, is higher than that at Dover by 108·5 feet.

The above experiment was actually made while sitting in a railway-carriage, and the example will serve as a guide for taking any measurement by the barometer.

The natural philosopher is enabled, by means of the Aneroid, to discover the quantity necessary for thermometrical correction. He has only to expose the instrument to the temperature of the external air, (having set the hands in coincidence,) and afterwards place it before the fire, until the thermometer is at 100. Any variation of the hand, divided by the degrees of the thermometer, will give the quantity for each degree. Mr. Dent remarks of this instrument, that the quantity to be allowed for correction does not generally equal what is necessary for the correction of the mercurial barometer. The amount will be sometimes in defect, and at others in excess. So nearly is the Aneroid compensated for varying temperatures.

Mercurial Gauges for Steam Engines.

These useful appendages to the steam engine being either barometrical or thermometrical, this seems the proper place describe them. Where the length is not a consideration h barometric ones act well, but thermometric ones cannot be depended upon generally.

Fig. 38.

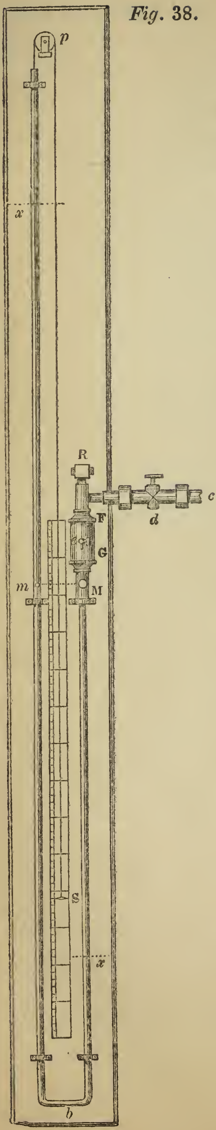


Fig. No. 38, is one of the forms in which mercury is employed to measure the pressure of steam when it is only a few pounds more pressure than that of the atmosphere. Steam is admitted from the boiler by the pipe *c*, and presses the mercury up the iron syphon tube M, *b*, *m*. Each 2 inches of rise is nearly equal to 1 lb. pressure above the atmosphere, which has access to the top of the mercury by the open end of the tube. A line from the float in this tube passes over the pully *p*, and is attached to the index S, to show the variation of pressure on the annexed scale. Gauges of this barometric form require to have a length equal to 2 inches for each pound of pressure, which makes them inconvenient at high pressures. It is thus constructed: M, *m*, R, are 3 openings fitted with suitable screws. These are taken out, and mercury poured in until it shows itself at M *m*, in each leg of the syphon, when these 2 holes are screwed up. Some water is then poured in at R, which is then also screwed up, and the instrument ready for use. The water prevents the heat of the steam oxidizing the mercury, which is found to injure its expansive action, and render its indications erroneous in thermometrical steam gauges.

Fig. 39.

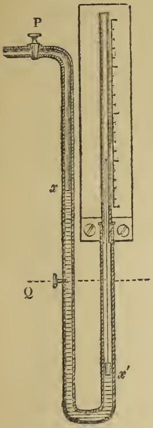


Fig. No. 39, is a different form, where the mercury is all contained in the tube *x x*, which has one end connected to the boiler by the pipe P, and the other end open to the atmosphere. The indications being given off on the attached scale of parts.

Fig. No. 40, is another form of mercurial gauge for condensers. A, a cup filled with mercury, in which the barometric tube is immersed, having the other end bent in the syphon form, and connected with the condenser of a low-pressure engine. On the cock P being opened, the pressure of the air on the mercury in the cup causes it to rise and indicate, on the scale of parts, the comparative vacuum produced in and power gained from the condenser.

Fig. 40.

In all these gauges the pressures indicated are the differences between the atmospheric pressure and the pressure in the boiler or in the condenser. In condensers the pressure will be less than the atmosphere by 2 inches for each pound pressure. In the boiler, the pressure will be greater than the atmosphere by 2 inches for each pound. So that a rise of 8 inches in the boiler gauge indicates steam of 4 lbs. pressure above the atmosphere, or 19 lbs. gross pressure, and a rise of 24 or 26 inches in the condenser gauge shows that a pressure of 12 or 13 lbs. has been added to the 4 lbs. pressure, making a working pressure of 16 or 17 lbs. per square inch from an apparent pressure of only 4 lbs.

Air Gauge.

Since the preceding gauges require a length of 2 inches of

mercury for each pound of pressure, they are inapplicable to pressures of 60 or 100 lbs. on locomotive boilers. In place of leaving the mercury exposed to the air at one end, and to the steam at the other end, air is confined in a Torricellian tube, closed at the upper end, and resting in a cup of mercury at the lower end, on which the force of the steam acts to compress the column of air, which then becomes the measure of the force of steam.

Fig. 41.

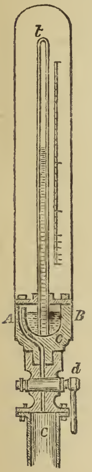


Fig. 42.

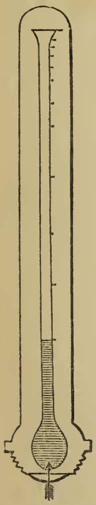
Fig. No. 41, will show their construction. *t t* the glass tube containing air, immersed in the cup A B of mercury, which rises to the level or pressure balanced by the mercury in the cup and the air in the tube, for the zero of the gauge. The volume of a given quantity of air being inversely as the space it occupies, a scale—starting at the gauge zero—is adjusted to this established law, to show the force of the steam by the diminished volume of the confined air. For instance, if the pressure be 20 lbs. and increased to 40 lbs., the volume of air would be reduced one-half, and at 60 lbs. to one-third the volume at 20 lbs., as will be further illustrated under the head of Expansive Force of Elastic Fluids. On steam being admitted by the stopcock *d* it presses upon the mercury in A B, which rises and compresses the air in the tube and indicates the force on the scale. Gauges of this class were employed by both the French Academy and Franklin Institutes in their valuable experiments on steam.

When carefully made and adjusted they are valuable instruments. On locomotive engines the passing current keeps the confined air from heating, which requires to be guarded

against, and if the scale is correctly adjusted the indications would be accordingly.

Fig. No. 42, is another form of this useful gauge, where very small holes in the bottom of the bulbous part of the tube admit the direct action of the steam on the mercury, whilst the reservoir at the top gives a larger volume of air to act against, with less risk of error.

Fig. 43.



When steam is freely admitted to act on mercury for a length of time, the mercury is found to deteriorate; or the loss of any portion of it from the tube or cup would affect the accuracy of the scale. Mr. Davies of Leeds states that he has, by using a larger column of mercury, greatly improved the accuracy and durability of mercurial steam gauges.

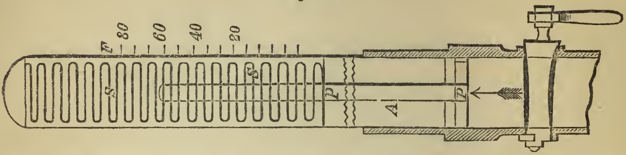
Thermometric gauges (Fig. No. 43) are similarly constructed to those already described for measuring heat by, and are designed to give the force of steam from its temperature. They have not yet, however, been successful for accuracy of indications. If the heat communicated to the bulb is partly lost in the ascent of the mercury, the upper portion would not equally expand with the lower portion; or if the bulb is ever so slightly compressed by the force of the steam, the indications in each instance would be incorrect.

The changing pressure in locomotive boilers from their small steam space and rapid consumption renders slight variations of temperature easily effected by atmospheric influence, or other disturbing causes. If the tube were of greater length and surrounded by an atmosphere of the same temperature as is in the boiler, thermometric gauges might be depended upon, but for ordinary locomotive purposes there are several impediments to their successful application.

Besides mercurial gauges, spring gauges have been made

of the form shown in Fig. No. 44, which is a small cylinder exactly one square inch area, whose piston P is made to com-

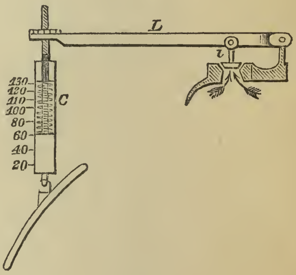
Fig. 44.



press the spiral spring S S, according to the force of the steam on the piston, and an index attached to the piston rod shows the force on a scale *F* adjusted to the spring. This is, in fact, Watt's indicator applied as a permanent gauge.

Salter's well-known spring balance, Fig. No. 45, also measures the pressure by the upward force of the steam on the safety valve *l*, compressing a double spiral spring within the cylindrical case C, by the action of the lever L, and showing the force on a scale of pounds.

Fig. 45.



CHAPTER II.

MECHANICAL FORCE OF STEAM.

This force is dependent upon the pressure under which steam is generated, for it varies in the ratio of that pressure. Under the atmospheric pressure of 15 lbs. per square inch, water boils at a temperature of 212°, and the steam evolved has a force of 15lbs. per square inch; but when the atmospheric pressure is wholly withdrawn by an air pump, water boils at a temperature as low as 70° and produces steam, having a force of about ⅓ of a lb. or · ·72 inches of mercury.

As 70° is a temperature considerably below that of the human body (98°), the heat of the hand would produce ebullition in a vacuum. For instance, if water were boiled in a glass phial, and corked whilst it still contained steam, it would on being withdrawn from the heat cease to boil; but if immersed in cold water boiling would recommence, because the cold had condensed the steam and removed the pressure from the water, but if again immersed in hot water steam would be formed, and the boiling cease from the increased pressure on the water. It is found by experiment that for every variation of one inch of mercury or one half pound on the pressure on the water the boiling point varies 1·76° as under :—

Barometer in Mer.	Boiling Point. Fahr.
27	206·9
27½	207·8
28	208·7
28½	209·5
29	210·4
29½	211·2
30	212·0
30½	212·8
31	213·6

For each 2·6 per cent. of common salt in water the boiling point rises 1°, and when it reaches 36 per cent. the water is said to be saturated with salt, and the boiling point raised to 226° or 228°.

Sea water contains about 3½ per cent. of saline matter, which has called forth ingenious processes of distilling salt water for marine boilers, or of brine pumps for removing these saline matters deposited by boiling, and which unless removed speedily obstruct the generation of steam. With 3 per cent. of saline matter water boils at 213·2° temperature and with 6 per cent. at 214·4°.

Steam is produced at all temperatures; even in freezing, natural evaporation may be seen, as if the river, streamlet or

lake were smoking; and it possesses mechanical force even at such low temperatures, as is shown in the following table by Dalton:—

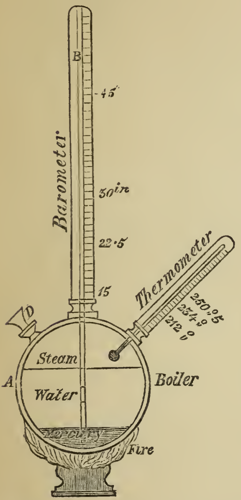
Table No. 35.

ELASTIC FORCE OF STEAM FROM 32° TO 212° IN INCHES OF MERCURY.

Temp. Deg.	Force. In. mer.	Temp. Deg.	Force. In. mer.	Temp. Deg.	Force. In. mer.	Temp. Deg.	Force. In. mer.	Temp. Fah.	Force. In. mer.
32	0·200	69	0·698	105	2·18	141	5·90	177	14·22
33	0·207	70	0·721	106	2·25	142	6·05	178	14·52
34	0·214	71	0·745	107	2·32	143	6·21	179	14·83
35	0·221	72	0·770	108	2·39	144	6·37	180	15·15
36	0·229	73	0·796	109	2·46	145	6·53	181	15·50
37	0·237	74	0·823	110	2·53	146	6·70	182	15·86
38	0·245	75	0·851	111	2·60	147	6·87	183	16·23
39	0·254	76	0·880	112	2·68	148	7·05	184	16·61
40	0·263	77	0·910	113	2·76	149	7·23	185	17·00
41	0·273	78	0·940	114	2·84	150	7·42	186	17·40
42	0·283	79	0·971	115	2·92	151	7·61	187	17·80
43	0·294	80	1·00	116	3·00	152	7·81	188	18·20
44	0·305	81	1·04	117	3·08	153	8·01	189	18·60
45	0·316	82	1·07	118	3·16	154	8·20	190	19·00
46	0·328	83	1·10	119	3·25	155	8·40	191	19·42
47	0·339	84	1·14	120	3·33	156	8·60	192	19·86
48	0·351	85	1·17	121	3·42	157	8·81	193	20·32
49	0·363	86	1·21	122	3·50	158	9·02	194	20·77
50	0·375	87	1·24	123	3·59	159	9·24	195	21·22
51	0·388	88	1·28	124	3·69	160	9·46	196	21·68
52	0·401	89	1·32	125	3·79	161	9·68	197	22·13
53	0·415	90	1·36	126	3·89	162	9·91	198	22·69
54	0·429	91	1·40	127	4·00	163	10·15	199	23·16
55	0·443	92	1·44	128	4·11	164	10·41	200	23·64
56	0·458	93	1·48	129	4·22	165	10·68	201	24·12
57	0·474	94	1·53	130	4·34	166	10·96	202	24·61
58	0·490	95	1·58	131	4·47	167	11·25	203	25·10
59	0·507	96	1·63	132	4·60	168	11·54	204	25·61
60	0·524	97	1·68	133	4·73	169	11·83	205	26·13
61	0·542	98	1·74	134	4·86	170	12·13	206	26·66
62	0·560	99	1·80	135	5·00	171	12·43	207	27·20
63	0·578	100	1·86	136	5·14	172	12·73	208	27·74
64	0·597	101	1·92	137	5·29	173	13·02	209	28·29
65	0·616	102	1·98	138	5·44	174	13·32	210	28·84
66	0·635	103	2·04	139	5·59	175	13·62	211	29·41
67	0·655	104	2·11	140	5·74	176	13·92	212	30·00
68	0·676								

To produce steam of a pressure greater than the atmosphere, requires the water to be boiled in a close vessel until it has attained the force necessary to perform its mechanical duty.

Fig. 46.



The gradual accumulation of that force in a steam boiler, and the ratio of the temperature to that force are illustrated in Fig. No. 46, which represents a spherical boiler partly filled with mercury and partly filled with water. B, a barometric glass tube open at both ends, reaching nearly to the bottom of the mercury. C, a thermometer with its end reaching nearly to the surface of the water. D, the supply cock for filling the boiler. On heat being applied below the boiler whilst the supply cock D is open, the steam will pass out as formed at a temperature of 212°, and the mercury remain stationary by the pressure of the atmosphere on it in the tube B being equal to the pressure of the steam on the water in the boiler A. If D be then shut this equality of pressure ceases, and the mercury begins gradually to ascend the tube in the ratio of the accumulating force of the steam above the force of the atmosphere. The thermometer also rises by the increased temperature of the steam. Now, if the pressure of the steam has raised the mercury 15 inches in the tube B, indicating a force of $7\frac{1}{2}$ lbs. above that of the atmosphere, the thermometer will have risen to 234°, being the heat of that pressure. At $250\frac{1}{2}$° the mercury in the tube will have risen 30 inches, showing a pressure of 15 lbs. above the atmosphere with a temperature of 250·5°, or an actual pressure of 30 lbs. per square inch on the water. If the cock D be now opened the steam will rush out,

thermometer rapidly fall to 212°, and the mercury in the tube B to zero again. The elastic or mechanical force of steam increases in a greater ratio than its temperature, for at 212° its force is 15 lbs., at $250\frac{1}{2}$° it is 30 lbs., and at 285° it is $52\frac{1}{2}$ lbs. The first $38\frac{1}{2}$° increases the force 15 lbs., but by $34\frac{1}{2}$° more heat its force is increased $22\frac{1}{2}$ lbs.

The following table shows this ratio of increase at various temperatures:

TABLE No. 36.

Temp. Deg. Fah.	FORCE OF STEAM IN				
	Atmospheres.	Open tube. In. mer.	Bar. tube. In. mer.	Above atm. lbs. avoir.	Full force. lbs. avoir.
212	1	0	30	0	15
230·96	$1\frac{1}{2}$	15	45	7·5	22·5
253·52	2	30	60	15·	30·
293·72	4	90	120	45	60
341·96	8	210	240	105	120
398·48	16	450	480	225	240
433·56	22	690	720	360	375

From this it is seen, that while the temperature is little more than doubled, the force is increased from 15 to 345 lbs. or 23 times. If it were not for this increasing force in proportion to the additional heat introduced, high-pressure steam engines would, for all ordinary pressures, be unable to enter into an economical competition with condensing engines. For instance, the working pressure of 4 lbs. steam has been shown to be 16 lbs. Its relative volume to water is 1411, but the p157
relative volume of high-pressure steam of 31 lbs. or 16 lbs. working pressure is only 857, or less than five-eighths of the volume or cylinders-full of the low-pressure steam.

The mechanical force of steam above atmospheric pressure is thus given by Taylor:

Table No. 37.

FORCE OF STEAM FROM 212° TO 320° IN INCHES OF MERCURY.

Temp. Deg.	Force. In. mer.	Temp. Deg.	Force. In. mer.	Temp. Deg.	Force. In. mer.	Temp. Deg.	Force. In. mer.	Temp. Deg.	Force. In. mer.
212	30·00	234	44·60	256	65·50	278	94·70	300	135·75
213	..	235	45·50	257	66·60	279	96·26	301	135·60
214	31·00	236	46·40	258	67·75	280	97·75	302	137·55
215	..	237	47·30	259	69·00	281	99·25	303	139·75
216	32·30	238	48·20	260	70·12	282	100·70	304	141·90
217	33·00	239	49·10	261	71·25	283	102·20	305	144·05
218	33·70	240	50·00	262	72·45	284	103·80	306	146·15
219	34·20	241	50·90	263	73·52	285	105·60	307	148·30
220	35·00	242	51·75	264	74·80	286	107·30	308	150·65
221	35·50	243	52·62	265	76·00	287	109·00	309	157·70
222	36·20	244	53·50	266	77·25	288	110·80	310	155·00
223	37·00	245	54·40	267	78·50	289	112·65	311	157·20
224	37·50	246	55·30	268	79·80	290	114·50	312	159·45
225	38·00	247	56·25	269	81·14	291	116·40	313	161·75
226	38·80	248	57·20	270	82·50	292	118·30	314	164·20
227	39·50	249	58·20	271	83·90	293	120·25	315	166·70
228	40·20	250	59·12	272	85·45	294	122·20	316	169·15
229	40·85	251	60·10	273	86·95	295	124·15	317	171·70
230	41·55	252	61·12	274	88·50	296	126·05	318	174·30
231	42·25	253	62·15	275	90·00	297	128·00	319	176·80
232	43·00	254	63·20	276	91·55	298	129·80	320	179·40
233	43·75	255	64·40	277	93·15	299	131·62		

Condensation of Steam.

This is an important source of economy in a low-pressure engine, and was first economically applied by Watt employing a separate cylinder for condensation; but before his time it had been condensed in the working cylinder, causing a great loss of heat each stroke of the engine.

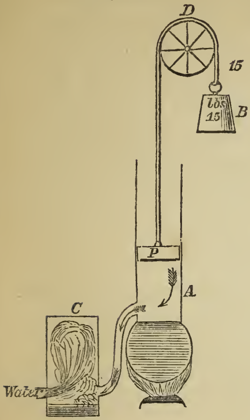
By Watt's plan, the steam now passes from the working cylinder into another one called the condenser, into which water is introduced to condense the steam. In Fig. No. 46, (see p. 163,) if, instead of opening the cock D, water had been introduced by

that pipe to the boiler A, the steam would have been condensed, and the temperature and pressure reduced accordingly. The quantity of water required for condensation is considerable. If the total heat of steam of 15 lbs. pressure is nearly 1178°, the water required for condensation would be indicated by the amount of heat to be abstracted from the steam and absorbed by the water. If we take the heat of water as 52°, and of steam as 1178°, their difference is 1126°, to be divided by the quantity of heat which can be absorbed by the water without impairing the vacuum in the condenser. If this be taken as 40°, we have $\frac{1126}{40} = 28$ times, but if it be taken as 60°, which can be so absorbed, we have $\frac{1126}{60} = 18{\cdot}7$ times, or 28 times, as the respective quantities of water required for condensation, or from 18 to 28 times the quantity necessary to form the steam, but variable according to the temperature of the condenser and condensing water. Since locomotive engines require tanks holding from 1400 to 1700 gallons of water for steam only, it will be seen that to carry about 20 times that quantity, or from 120 to 150 tons additional, would be a load of itself, besides the more complicated machinery of a condensing engine. Whilst water remains the agent of condensation, these are palpable difficulties in applying this plan to locomotives, although some ingenious attempts have been made by Mr. Adams to do so on an engine at the Eastern Counties Railway.

The economy of condensing engines arises from their using low-pressure steam, which has a large volume, and the additional pressure derived from the vacuum in the condenser. For if this vacuum is equal to 12 lbs., it adds that amount to the pressure in the boiler above the atmosphere, less the friction of the condensing machinery.

This pressure of 12 lbs. is that portion of the atmospheric pressure which is unbalanced by the pressure in the condenser,

Fig. 47.



and may be illustrated by diagram No. 47, where A is a glass tube having a bulb at one end containing water, and fitted with the piston P. On heat being applied steam will be produced and the piston forced up to the top of the tube, and if the tube be then immersed in cold water the steam will be condensed, and the pressure of the air force the piston down again.

This, however, would also cool the cylinder, requiring as much heat to raise it again to the steam temperature, a double source of expence, but when conveyed to the separate cylinder C this loss is avoided. The downward pressure of the air would then be indicated exactly by a weight B suspended from the piston P over the pulley D, and over a perfect vacuum this would be $14\frac{3}{4}$, or say 15 lbs. per square inch in whole numbers.

Volume, Force, and Condensation of Steam.

If the cylinder A, Fig. No. 47, were 1 square inch area by 1700 inches high, it would contain 1 cubic inch of water converted into steam of atmospheric pressure, and this steam would raise 15 lbs. to that height (nearly 142 feet). It is found that the volume of steam at that pressure is very nearly 1700 times that of the water which produced it, hence the weight which the steam would raise being multiplied by the height, gives the effect produced by 1 cubic inch of water as steam = 142 ft. × 15 lbs. = 2130 lbs. raised 1 foot high. By condensing the steam into water again the atmosphere would force the piston down through an equal distance with an equal effect; or if the cylinder was made air-tight at top, and steam of atmospheric pressure introduced, a like result would take place.

If the pressure of steam is raised to 30 lbs. per inch, its volume is diminished to only 883 times that of the water which produced it, or equal to a height of $73\frac{1}{2}$ ft. × 30 lbs. pressure = 2205 lbs. as its mechanical force. At 100 lbs. per inch the volume of steam to water is as 295 to 1, or 24·58 ft. and 24·58 × 100 = 2458 lbs. raised 1 foot. This shows that the effect increases slowly with the pressure; but it is usual to take the mechanical value of 1 cubic inch of water as equal to raise 1 ton 1 foot high, and the complete condensation of 1 cubic inch of water as of an equivalent value.

This gradual diminution of bulk from increased pressure is nearly as given in TABLE NO. 38.

Taking the steam produced under a pressure of 15 lbs. per square inch as one volume, or unity, the ratio of bulk to other pressures is approximately

Lbs.		Volume.		Spaces.	BY EXPERIMENT. Lbs.	Volume.	Lbs.	Volume.
15	=	1	or say	50	5	4617	75	383
					6	3897	80	362
30	about	·5	or	$\frac{25}{50}$	7	3376	90	325
					10	2426	100	295
45	,,	·36	,,	$\frac{18}{50}$	12	2050	110	271
					15	1669	120	251
60	,,	·28	,,	$\frac{14}{50}$	16	1573	130	233
					18	1411	140	218
75	,,	·22	,,	$\frac{11}{50}$	20	1281	150	205
					30	883	160	193
90	,,	·18	,,	$\frac{9}{50}$	40	679	170	183
					45	610	180	174
150	,,	·16	,,	$\frac{8}{50}$	50	554	190	66
					60	470	200	158
120	,,	·14	,,	$\frac{7}{50}$	70	408		

Since each succeeding addition of pressure diminishes the volume of steam, causing it to act through a shorter and shorter distance, although with greater force through that distance, it follows that increased pressure requires an increased supply of both heat and water to produce a volume of steam corresponding to low-pressure steam. The power would be

increased in the ratio of the pressure and diameter of the cylinder; but if no increase of power is required, a smaller cylinder or greater expansive action would be necessary to economy.

The frictional surface of a small piston is, however, greater for its area of acting surface than a large one, whilst an increase of pressure gives corresponding advantages to the larger piston, as seen in the following table:

TABLE, No. 39.

COMPARATIVE RUBBING AND PRESSING SURFACES OF PISTONS, WITH INCREASING POWER FOR EACH ADDITIONAL 10 LBS. PER SQUARE INCH.

Diam.	PISTON.			Power for each 10 lbs. press. on the piston.
	Rubbing surface, or circumference.	Acting surface, or area.	Ratio of acting to rubbing.	
Inch.	Lineal inch.	Square inch.	Rub. = 1.	lbs.
6	18·849	28·274	$1\frac{1}{2}$	282·7
7	21·991	38·484	$1\frac{3}{4}$	384·8
8	25·132	50·265	2	502·6
9	28·274	63·617	$2\frac{1}{4}$	636·1
10	31·416	78·54	$2\frac{1}{2}$	785·4
11	34·557	95·03	$2\frac{3}{4}$	950·3
12	37·699	113·097	3	1130·9
13	40·84	132·732	$3\frac{1}{4}$	1327·3
14	43·98	153·938	$3\frac{1}{2}$	1539·3
15	47·124	176·715	$3\frac{3}{4}$	1767·1
16	50·265	201·062	4	2010·6
17	53·407	226·98	$4\frac{1}{4}$	2269·8
18	56·548	254·469	$4\frac{1}{2}$	2544·6
19	59·69	283·529	$4\frac{3}{4}$	3835·2
20	62·832	314·16	5	3141·6
21	65·793	346·36	$5\frac{1}{4}$	3463·6
22	69·115	380·13	$5\frac{1}{2}$	3801·3
23	72·256	415·476	$5\frac{3}{4}$	4154·7
24	75·398	452·39	6	4523·9

By this table it is seen that whilst a 9-inch piston has an area of only $2\frac{1}{4}$ times its boundary or rubbing surface, an 18-inch piston has an area of double that ratio, or $4\frac{1}{2}$ times its circumference. The depth of the respective pistons may slightly but not materially alter this ratio, whilst the increase of power for an additional 10 lbs. of pressure on each square inch is for the 9-inch piston 636 lbs., and for the 18-inch piston 2544 lbs., or four times that of the smaller piston.

Volume of Steam.

In determining the size of cylinder for any given pressure, or for any given boiler, the volume of steam is a necessary element in the calculation, and for this purpose the following rules are submitted for ordinary steam. They are based on the ascertained facts that steam of atmospheric pressure is very nearly 1700 times the volume of the water which produced it; and that for each additional degree of heat of Fahrenheit's scale, steam expands when in contact with water, ·00202 times its bulk, hence for any other pressure we have:

$$\text{Volume} = \frac{1700 \times 14{\cdot}75}{\text{pressure}} \times \frac{1 \times {\cdot}00202\ (\text{temp.}-32)}{1 \times {\cdot}00202 \times 180}$$

The following rules are very simple in their application:

By Pambour,

$$\text{Volume} = \frac{10000}{1{\cdot}421 \times {\cdot}331\ \text{pressure}}$$

Pole gives,

$$\text{Volume} = \frac{24250}{\text{pressure}} + 65$$

Ex.—Required the volume of steam of 100 lbs. pressure per square inch relatively to water as 1?

By Pambour,

$$\frac{10000}{100 \times {\cdot}331 \times 1{\cdot}421} = 289{\cdot}6 \text{ times.}$$

By Pole,

$$\frac{24250}{100} + 65 = 307{\cdot}5$$

or a difference of nearly 18 volumes of the water forming the steam.

The volume may also be found by adding 4·29 to the pressure in pounds per square inch, and deducting the logarithm of this sum from 4·4799. The natural number of the remainder will give the ratio of the volume of steam to water.

For the last example we have—

$$\log. \text{ of } 100 + 4{\cdot}29 = 2{\cdot}0182; \text{ and } 4{\cdot}4799 \text{ less } 2{\cdot}0182 = 2{\cdot}4617$$

and the natural number of 2·4617 = 289·4

or nearly the same as Pambour's formula gives.

Tate's formula is, volume = 12·5 + 20570 pressure—·9301, which gives very near results to experiment, but it is of a more complex description than those previously given.

The volume of steam under expansion may be found by adding 459, to the respective temperature, before and after expansion, and dividing the greater by the lesser sum. The volume due to the lowest temperature multiplied by the quotient will give the volume for the highest temperature.

Frost's experiments on heating steam separated from water show a very different ratio of expansion. At the temperature of 216° the volume was doubled, at 228° it was trebled, and at 650° it was more than seven times the volume at 212°, or upwards of eight volumes altogether. Whether the manner of conducting these experiments had anything to do with the results or not, they sufficiently indicate that further investigation is necessary to determine the volumes of steam from direct experiment, and not as generally by comparison with permanent gases, more particularly at high temperatures.

Velocity of Steam.

Steam is estimated to flow into a vacuum with a velocity equal to that due to a body of the same density falling through a space equal to the height of a column of steam of the given pressure. For instance, it would require a column

of steam about 63500 feet high to give a pressure of 45 lbs. upon a square inch. The velocity due to the pressure may be found by adding 4·29 to the pressure in pounds per square inch, and deducting the logarithm of this sum from the logarithm of the pressure. To one-half the remainder add 3·3254, and the natural number of this sum will be the velocity in feet per second.

Example. Required the velocity with which steam of 100 lbs. pressure would rush into a vacuum?

Pressure 100 lbs. whose log. = 2·00000
and pressure 100 + 4·29 = 104·29 whose log. = 2·01828

and remainder ÷ $\frac{1}{2}$) $\bar{9}$·98172

leaves $\bar{9}$·99086
to which add 3·3254

gives 3·31626 whose natural number = 2071 feet per second.

Table, No. 40.

VELOCITY OF STEAM IN FEET PER SECOND, BY THIS RULE.

Pressure.	Velocity in feet.	Pressure.	Velocity in feet.	Pressure.	Velocity in feet.
lbs.	per second.	lbs.	per second.	lbs.	per second.
5	1552	80	2061	155	2085·3
10	1770	85	2064	160	2086
15	1856	90	2067	165	2086·7
20	1919	95	2069	170	2087·5
25	1955	100	2071	175	2088·3
30	1978	105	2073	180	2089
35	1997	110	2075	185	2089·7
40	2010	115	2077	190	2090·5
45	2021	120	2079	195	2091·3
50	2030	125	2080	200	2092
55	2037	130	2081	205	2092·7
60	2043	135	2082	210	2093·5
65	2049	140	2083	215	2094·3
70	2053	145	2083·7	220	2095
75	2057	150	2084·5	250	2132

The difference between the velocities of any two pressures is

the velocity with which steam would flow into steam of a lower pressure. Thus, steam of 120 lbs. gross pressure, would flow into steam of 20 lbs. pressure, at a velocity of $2079 - 2010 = 69$ feet per second.

Such is the estimated velocity of steam when there are no frictional obstructions to its passage; but, as these are conditions not obtainable in practice, the velocity will be reduced in proportion to the resistances it has to overcome. In locomotive engines at high velocities these resistances are very considerable; for, with a back pressure from $\frac{1}{16}$ to $\frac{1}{4}$ of that in the boiler, narrow steam-ports, incomplete exhaustion, and rapid action of the slide, this velocity it is evident must be very materially lessened. Those who have carefully observed indicator cards will have seen that the steam in the cylinder, only attains a force near that in the boiler, when the resistances against the piston retard its progress until such force has accumulated; but, if the resistance does not require that force, the piston moves on more rapidly than allows time for such accumulation.

The steam may, therefore, be 100 lbs. in the boiler; but, if 35 lbs. will overcome the resistances againt the piston, including the back pressure, the piston will move on with a velocity to prevent a greater pressure. Yet if that piston were arrested, even for a second, the pressure would equalize itself very nearly in the boiler and in the cylinder. This indicates that the velocity of the steam, in passing from the boiler to the cylinder, is not so great but that the motion of the piston sensibly affects its accumulation there. Since 1000 feet per minute is an extreme velocity for a piston, it leads to the conclusion that the actual velocity of steam, in a locomotive engine, is moderate; but what the exact velocity may be remains to be determined by experiments.

Temperature and Force of Steam.

To determine the relation between the force and tempera-

ture of steam a great many experiments have been made, both in Europe and America. In 1762, Watt commenced the modern investigations of the properties of steam, and his splendid practical success gave an impetus to such inquiries, which has not been exhausted. In 1829, the French Academy of Science appointed a Committee to solve the question by experimental research on a most elaborate scale. These experiments were conducted by Messrs. Arago and Dulong, aided by the best instruments, and their own extensive knowledge of natural philosophy. Having decided, on testing, the force of steam by a barometric tube filled with mercury, they had one made in 13 pieces, each $78\frac{3}{4}$ inches long, to join together so as to form one enormous glass tube, having a bore of about $\frac{1}{5}$ of an inch diameter for the mercurial column. This was erected against the old church tower of Genevieve, and experiments made to determine the accuracy of Mariotte's law of air, that its pressure or force is inversely as the space a given quantity is made to occupy. Having found this law very nearly correct to the high pressure of 24 atmospheres, and as the fears of the authorities for the old Tower from an explosion of the boiler led the large barometer to be taken down, they employed carefully constructed air-gauges similar to figs. Nos. 41, 42, to determine the force of the steam. One thermometer was placed in the boiler to ascertain the temperature of the steam, as in fig. No. 46, and another placed nearly to the bottom of the water, that the temperature of both water and steam might be ascertained at once, which were found to correspond exactly, and the steam to be of the same temperature as the water which produced and was in contact with it.

The compression of the air in the gauge, by the force of the steam acting on the mercury, gave its pressure at the same time; so that the force and temperature were simultaneously determined at the same instant up to 24 atmospheres, and by calculation extended to 50 atmospheres, as given in the following table.

Table, No. 41.

MESSRS. ARAGO AND DULONG'S EXPERIMENTS OF THE TEMPERATURE AND PRESSURE OF STEAM.

Atmospheres.	Deg. Fah.	Deg. Cent.	lbs. per Inch.	Kil. per sq. Centi.
1	212	100	14·706	1·0335
1½	233·96	112·2	22·059	1·5502
2	250·52	121·4	29·412	2·067
2½	263·84	128·8	36·765	2·5837
3	275·18	135·1	44·118	3·1005
3½	285·08	140·6	51·471	3·6172
4	293·72	145·4	58·824	4·134
4½	300·30	149·6	66·177	4·6507
5	307·54	153·1	73·53	5·1675
5½	314·24	156·8	80·883	5·7842
6	320·36	160·2	88·236	6·2010
6½	326·26	163·48	95·589	6·7177
7	331·70	166·5	102·942	7·2345
7½	336·86	169·37	110·295	7·7512
8	341·78	172·1	117·648	8·268
9	350·78	177·1	132·354	9·3015
10	358·88	181·6	147·060	10·3350
11	366·85	186·0	161·766	11·3685
12	374·00	190·0	176·472	12·402
13	380·66	193·7	191·178	13·435
14	386·94	197·19	205·884	14·469
15	392·86	200·48	220·59	15·5025
16	398·48	203·6	235·296	16·536
17	403·82	206·5	250·002	17·5695
18	408·92	209·4	264·708	18·6030
19	413·78	212·2	279·414	19·6365
20	418·46	214·7	294·120	20·67
21	422·96	217·2	308·826	21·7035
22	427·28	219·6	323·532	22·7370
23	431·42	221·9	338·238	23·7705
24	435·56	224·2	352·944	24·8040
25	439·34	226·3	367·650	25·8375
30	457·16	236·2	441·18	31·005
35	472·73	244·85	514·71	36·1725
40	486·59	252·55	588·24	41·34
45	499·13	259·52	661·77	46·5075
50	510·60	265·89	735·33	51·6750

After mathematically analysing the results of these experiments, and the law by which they were extended to 50 atmospheres, and reviewing the previous laws of Tredgold and others, Pambour gives the following useful table as a close approximation to the real values of steam.

TABLE, No. 42.

PRESSURE, TEMPERATURE, AND RELATIVE VOLUME OF STEAM TO THE WATER THAT PRODUCED IT, TAKING THE WATER AS UNITY OR 1.

Pressure per square inch.	Temp.	Volume of water being 1.	Pressure per square inch.	Temp.	Volume of water being 1.	Pressure per square inch.	Temp.	Volume of water being 1.
lbs.	Fah.	No.	lbs.	Fah.	No.	lbs.	Fah.	No.
1	102·9	20954	38	265·3	710	75	308·9	381
2	126·1	10907	39	266·9	693	76	309·9	377
3	141·0	7455	40	268·4	677	77	310·8	372
4	152·3	5695	41	269·9	662	78	311·7	368
5	161·4	4624	42	271·4	647	79	312·6	364
6	169·2	3901	43	272·9	634	80	313·5	359
7	176 0	3380	44	274·3	620	81	314·3	355
8	182·0	2985	45	275·7	608	82	315·2	351
9	187·4	2676	46	277·1	596	83	316·1	348
10	192·4	2427	47	278·4	584	84	316·9	344
11	197·0	2222	48	279·7	573	85	317·8	340
12	201·3	2050	49	281·0	562	86	318·6	337
13	205·3	1903	50	282·3	552	87	319·4	333
14	209·0	1777	51	283·6	542	88	320·3	330
15	213·0	1669	52	284·8	532	89	321·1	326
16	216·4	1572	53	286·0	523	90	321·9	323
17	219·6	1487	54	287·2	514	91	322·7	320
18	222·6	1410	55	288·4	506	92	323·5	317
19	225·6	1342	56	289·6	498	93	324·3	313
20	228·3	1280	57	290·7	490	94	325·0	310
21	231·0	1224	58	291·9	482	95	325·8	307
22	233·6	1172	59	293·0	474	96	326·6	305
23	236·1	1125	60	294·1	467	97	327·3	302
24	238·4	1082	61	294·9	460	98	328·1	299
25	240·7	1042	62	295·9	453	99	328·8	296
26	243·0	1005	63	297·0	447	100	329·6	293
27	245·1	971	64	298·1	440	105	333·2	281
28	247·2	939	65	299·1	434	120	343·3	249
29	249·2	909	66	300·1	428	135	352·4	224
30	251·2	882	67	301·2	422	150	360·8	203
31	253·1	855	68	302·2	417	165	368·5	187
32	255·0	831	69	303·2	411	180	375·6	173
33	256·8	808	70	304·2	406	195	382·3	161
34	258·6	786	71	305·1	401	210	388·6	150
35	260·3	765	72	306·1	396	225	394.6	141
36	262·0	746	73	307·1	391	240	400·2	133
37	263·7	727	74	308·0	386			

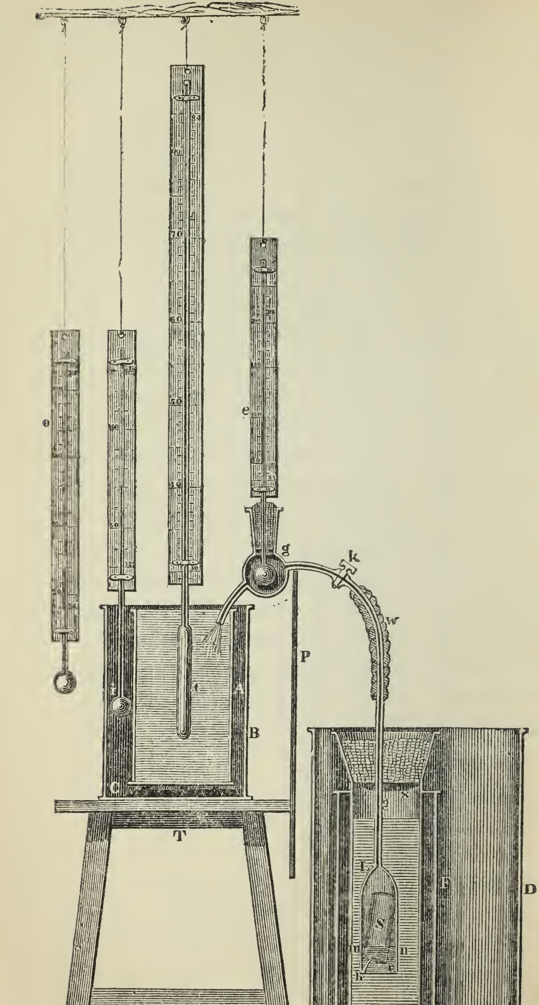
In 1832-3 The Franklin Institute of America made a series of elaborate experiments to determine the diffused heat in steam of 212° to 215°, by condensing a given weight of steam in a given quantity of water.

Fig. No. 48, shows the method adopted and care exercised to obtain accurate results. F, the boiler into which the copper vessel L, containing the heater S, was placed to sustain the temperature of the boiler during the trial. W, *k*, *g*, a pipe for conveying the steam to the condenser A, filled with a known quantity of water. The steam was allowed to flow from the boiler and condense until the condenser was filled, when it was shut off by the cock *k*. The condenser and contents being then accurately weighed showed the weight of steam which had been condensed, and the thermometer *t* showed the increase of the temperature of the water in A. Of the three other thermometers, *e* showed the temperature of the steam, *i* the temperature within the radiation protector B, and o the surrounding temperature of the apartment.

These thermometers were all carefully adjusted and corrections made for their respective duties, and both condenser and boiler incased to prevent loss of heat by radiation. A reflecting tin plate, P, was also placed between them, to guard against the least influence from the boiler affecting the condenser.

The principal results are given in table No. 43.

Fig. No. 48.



Table, No. 43.

LATENT OR DIFFUSED HEAT IN STEAM.

STEAM.			WATER.				DIFFUSED HEAT.	
Temp. before condensation.	Temp. lost by condensation.	Quantity condensed.	Condenser, made of.	Quantity in condenser.	Temp. before the admission of steam.	Temp. increased by the condensation of the steam admitted.	In each experiment.	Mean of experiments.
Fah.	Fah.	Grains	Material.	Grains	Fah.	Fah.	Fah.	Fah.
214	127·5	347	thin copper.	38659	75·35	10·75	1086·5	
215	129·25	504	,,	38659	70·9	14·85	1025·5	
215	139·25	241	,,	39305	68·75	7	1018·95	
214	136·75	250	,,	39305	70	7·25	1019·55	
								1037·87
213	120·35	299	thick glass.	17112	74·6	18·05	996·9	
215	127	192	,,	17112	75·5	12·5	1077·82	
214	139·5	156	,,	17428	64·6	9·9	1044·8	
213	139·75	127	,,	17428	65·25	8	1035·75	
								1038·51
213	134·2	167	thin glass.	18405	68·5	10	987·3	
212	143·5	156	,,	17428	58·5	10	1003·3	
								995·3
213	123·8	169	thick sheet iron.	13152	75·1	14·1	1027·2	
214	124·2	190	,,	13152	73·7	16·1	1043·5	
								1035·35

Having made these experiments on diffused heat the Committee extended their researches to ascertain the relation between the temperature of the steam and its elastic force. For this purpose they employed a small boiler 12 inches diameter and 34¼ inches long, having a glass window in each end for observation, besides the usual gauge-cock and glass water-gauge. A mercurial cistern was attached to the boiler, and

into the cistern was fitted, steam tight, an air-gauge 26·43 inches long, of the class fig. No. 41, having its open end in the mercury. A scale of pressures having been carefully adjusted to this gauge-tube, thermometers were applied to test the temperature of the water and of the steam in the boiler. Much care was taken to obtain accurate results from the pressure of the steam on the gauge, and to note at the same time the temperature indicated by the thermometers.

As with all other experiments on steam and water in contact with each other, the temperature was ascertained to be the same in both.

When the first trials were completed it was found that they differed considerably from those of the French Academy, when they were repeated with all the advantage of experience and precaution gained from the first series. The results of both series are given in Tables, Nos. 44, 45, and Table No. 46, is a summary of the mean pressures in atmospheres.

Table, No. 44.

ELASTIC FORCE OF STEAM BY THE FRANKLIN INSTITUTE.

(*First Series of Experiments.*)

Temp. of steam.	Temp. of air in steam-gauge.	Volumes of air at 48°	Height of mercury in steam-gauge.	Compressure on air in steam-gauge equal to	Total elasticity per square inch, in	
Fahr.	Fahr.	Vols.	In. mer.	In. mer.	In. mer.	Atmos. of 30 in. mer.
262¼	74	3·737	15·04	59·09	72·99	2·43
268½	,,	3·259	16·34	67·76	82·97	2·76
275½	,,	2·898	17·34	76·20	92·42	3·08
286½	,,	2·319	18·94	95·23	113·07	3·77
296½	,,	1·948	19·94	113·36	132·21	4·41
298½	,,	1·891	20·11	116·76	135·80	4·53[2]
302	,,	1·767	20·44	124·98	144·33	4·81[3]
305½	75	1·641	20·79	134·57	154·28	5·14
513¼	,,	1·422	21·39	155·30	175·61	5·85[4]
317¾	,,	1·332	21·64	165·79	186·36	6·21
320¾	76	1·255	21·79	173·20	193·92	6·46
327¾	,,	1·113	22·24	198·41	219·14	7·30
333¾	,,	0·950	22·69	232·46	254·09	8·47

Table, No. 45.

ELASTIC FORCE OF STEAM BY THE FRANKLIN INSTITUTE.

(Second Series of Experiments.)

Temp. of steam.	Temp. of air in steam-gauge.	Volumes of air at 48°	Height of mercury in steam-guage.	Compressure on air in steam-gauge equal to	Total elasticity per square inch, in	
Fahr.	Fahr.	Vols.	In. mer.	In. mer.	In. mer.	Atmos. of 30 in. mer.
248¼	53	4·277	14·04	46·19	59·08	1·97
269½	52	3·026	17·34	65·29	81·51	2·72
284½	,,	2·152	19·64	91·76	110·30	3·68
289½	,,	1·974	20·06	100·05	119·02	3·97
294½	53	1·802	20·56	109·63	129·11	4·30
299½	54	1·611	21·04	122·66	142·62	4·75
304½	54½	1·500	21·34	131·66	151·92	5·06
310¼	,,	1·382	21·64	142·94	163·51	5·45
314¾	55	1·233	22·04	160·26	181·23	6·04
319¾	55½	1·124	22·34	175·86	197·13	6·57
329¾	56	0·937	22·84	210·84	232·62	7·75
334½	57	0·904	22·94	218·60	240·48	8·02
338¾	57½	0·870	23·04	226·92	548·92	8·30
345	,,	0·805	23·24	245·44	267·62	8·92
348	58	0·771	23·34	256·05	278·33	9·28
350	,,	0·737	23·44	267·97	290·35	9·68
352	,,	0·719	23·50	274·92	297·36	9·91
346	62	0·785	23·28	251·78	274·00	9·13

Table, No. 46.

MEAN ELASTIC FORCE OF STEAM, FROM THE FRANKLIN EXPERIMENTS IN ATMOSPHERES.

Pressure.	Observed Temp.	Pressure.	Observed Temp.	Pressure.	Observed Temp.	Pressure.	Observed Temp.
Atmos.	Fahr.	Atmos.	Fahr.	Atmos.	Fahr.	Atmos.	Fahr.
1	212	3½	284	6	315½	8½	340½
1½	235	4	291½	6½	321	9	345
2	250	4½	298½	7	326	9½	349
2½	264	5	304½	7½	331	10	352½
3	275	5½	310	8	336		

M. Regnault has recently concluded an elaborate series of experiments on the heat and force of steam for the French Government. The practical results of these valuable experiments are given in tables Nos. 47—49. From these tables it appears that there is a regular increase in the total heat of steam up to the extent of these trials, or to 13·6 atmospheres. accompanied by a gradual decrease of diffused heat. It had hitherto been held that the heat of steam was the same for all pressures, but Mr. Regnault shows an increase of 45° from a pressure of 15 lbs. to one of 200 lbs. This is, however, so small an increase that it could scarcely develope itself at the low pressures experimented on by Watt and Southern, who differed as to whether it was the sensible or diffused heat of steam which was constant. Watt's view was that the diffused heat was not constant, but could be found by deducting the thermometric heat from the total heat of steam. Southern held that the diffused heat was constant, and this heat added to the thermometric heat gave the total heat. Regnault's experiments show that neither are constant, but that the diffused heat decreases from 973° to 880° or 93°, and that the thermometric heat increases from 1186° to 1231° or 45°. The difference between Regnault and Watt is therefore 45°, and between Regnault and Southern 93°, over a range of pressure many

times greater than was experimented on by these early and able pioneers of steam engineering.

TABLE, No. 47.

EXPERIMENTS UNDER VERY LOW PRESSURES.

Experiments.	Pressure Milemetre.	Temperature.	Quantity by weight after condensation.	Quantity in calometer.	Temperature.	Temperature increased by condensation.	Total heat.	Absorbed by the steam.
No.	Mm.	Cent.	Grms.	Grms.	Cent.	Cent.	Units.	Units.
1	4·5	− 0·2	5·250	542·0	9·21	5·748	601·5	592·3
2	3·9	− 2·1	5·180	541·8	12·17	5·713	608·9	596·7
3	4·6	0·	5·127	541·8	12·44	5·624	605·8	593·4
4	7·7	+ 7·4	5·170	541·4	15·47	5·725	614·5	599·0
5	8·3	+ 8·5	5·262	541·3	16·47	5·815	613·5	597·0
6	7·8	+ 7·6	5·127	541·3	16·17	5·642	611·5	595·3
7	9·0	+ 8·6	5·178	541·0	18·74	5·592	603·0	584·3
8	10·3	+ 11·8	5·240	541·0	19·22	5·675	605·1	585·9
9	7·8	+ 7·6	5·220	541·0	19·21	5·738	613·8	594·6
10	11·9	+ 14·0	5·252	541·0	20·20	5·725	609·9	589·7
11	10·0	+ 11·4	5·152	541·0	20·31	5·557	602·7	582·4
12	11·5	+ 13·5	5·242	540·9	21·48	5·744	614·3	592·8
13	6·6	+ 5·2	5·271	540·8	21·72	5·761	611·9	590·2
14	5·3	+ 2·0	5·221	540·8	21·71	5·717	613·0	591·3
15	12·4	+ 14·7	5·200	540·4	23·05	5·694	615·4	592·4
16	8·3	+ 8·5	5·250	540·4	23·54	5·697	610·6	587·1
17	8·3	+ 8·5	5·195	540·3	22·81	5·626	609·7	585·9
18	8·6	+ 9·0	5·162	540·3	24·09	5·605	611·5	587·4
19	8·5	+ 8·9	5·216	540·3	24·10	5·676	611·7	587·6
20	13·1	+ 16·6	5·192	540·1	26·40	5·641	613·1	586·7
21	8·6	+ 8·3	5·085	540·0	27·57	5·523	614·1	586·5
22	7·2	+ 6·4	5·207	539·9	28·16	5·705	619·7	591·6

Table, No. 48.

HEAT OF STEAM BELOW ATMOSPHERIC PRESSURE.

STEAM.					WATER.			HEAT OF STEAM.		
Pressure.		Temperature.				Temperature.				
Milemetres of mercury.	Atmosphere of 14·706 lb.	Before condensation. Deg. Cent.	After condensation. Deg. Cent.	Quantity condensed.	Quantity in condenser.	Before the admission of steam.	After the condensation of steam.	Heat conducted to water, per min.	Total quantity.	Latent or diffused.
Mm.	Atm.	°	°	Grms.	Grms.	Cent.	Cent.	Cent.	Cent.	Cent.
488·75	0·643	88·11	19·62	1390·85	66538·2	6·82	12·8361	0·00350	633·4	545·3
483·31	0·636	87·83	17·90	1219·25	66545·4	6·65	11·2771	0·00350	633·1	545·3
449·84	0·592	85·97	20·33	1444·50	66737·8	7·20	13·2044	0·00350	628·4	542·0
437·16	0·575	85·24	19·21	1404·00	66538·5	6·40	12·8977	0·00350	628·6	543·4
436·62	0·574	85·20	18·64	1278·98	66545·3	6·91	11·7868	0·00350	631·7	546·5
430·92	0·567	84·88	17·74	1246·65	66545·6	6·30	11·4730	0·09850	629·9	545·0
401·40	0·528	83·08	22·53	1310·63	66540·0	10·61	11·9472	0·00345	628·9	545·8
394·92	0·519	82·66	21·63	1378·34	66534·9	9·05	12·6276	0·00345	631·0	548·8
369·80	0·486	81·03	21·05	1338·45	66542·4	8·85	12·2286	0·00340	628·8	547·8
363·36	0·478	80·60	22·31	1243·87	66534·4	11·02	11·3202	0·00340	627·7	547·1
360·12	0·474	80·37	22·14	1230·15	66535·0	10·93	11·2189	0·00340	628·8	547·8
357·13	0·470	80·17	19·44	1244·23	66543·5	8·05	11·4240	0·00340	630·2	550·0
348·22	0·458	79·55	17·01	979·10	66543·5	8·03	9·0240	0·00240	630·1	550·5
330·63	0·435	78·28	17·67	1174·26	66538·1	7·00	10·7537	0·00340	627·0	548·7
307·17	0·404	76·50	20·20	1457·37	66545·3	6·95	13·3304	0·00340	628·6	552·1
247·07	0·325	71·35	20·28	1462·02	66538·1	7·09	13·2773	0·00340	624·4	553·0
244·55	0·322	71·11	18·28	1264·00	66538·2	6·93	11·4712	0·00320	622·2	551·1
238·09	0·313	70·49	18·69	1294·22	66545·3	6·93	11·8348	0·00320	626·9	556·4
230·17	0·303	69·70	19·17	1359·50	66545·3	6·85	12·4115	0·00320	626·4	556·7
213·72	5·281	68·01	19·12	1390·98	66538·4	6·59	12·6183	0·00320	622·5	554·5
198·10	0·270	66·30	18·23	1297·23	66545·5	6·48	11·8259	0·00320	624·7	558·4
181·47	0·239	64·34	19·58	1424·83	66538·4	6·73	12·9255	0·00320	622·9	558·6
170·91	0·224	63·02	18·25	1284·34	66545·5	6·58	11·7109	0·00320	625·5	562·5

TABLE, No. 49.

HEAT OF STEAM OF ATMOSPHERIC PRESSURE.

STEAM.					WATER.			HEAT OF THE STEAM.	
Pressure in		Temperature.				Temperature.			
Milemetres of Mercury.	Atmosphere of 14·706lbs.	Before condensation. Deg. Cent.	After condensation. Deg. Cent.	Quantity condensed.	Quantity in condenser.	Before steam is admitted.	Increased after steam is condensed.	Total of steam. Deg. Cent.	Diffused or latent. Deg. Cent.
Mm.	Atm.	°	°	Grms.	Grms.	Cent.	Cent.	°	Cent.
746·52	0·983	99·49	21·50	949·10	66524·0	12·81	8·7441	633·3	533·81
746·55	0·983	99·49	24·80	1255·15	66520·4	13·40	11·4829	634·1	534·61
767·06	1·009	100·26	22·85	1287·88	66534·4	11·00	11·8532	635·2	534·96
765·94	1·008	100·22	21·98	1200·79	66534·4	11·00	11·0485	634·0	533·78
770·13	1·013	100·37	..	1316·85	66538·6	6·19	12·1728	633·4	533·03
768·37	1·011	100·31	..	1413·45	66538·1	6·96	13·0710	635·4	535·09
746·43	0·982	99·49	23·71	1231·10	66523·5	13·00	11·3471	635·8	536·31
745·71	0·981	99·46	23·38	1230·10	66523·1	13·09	11·3356	636·3	536·84
741·29	0·975	99·31	23·53	1240·23	66523·3	13·05	11·4284	636·4	537·09
740·82	0·975	99·28	24·16	1233·05	66522·5	13·27	11·3744	637·6	538·32
765·19	1·007	100·19	22·37	1272·84	66535·4	10·76	11·7391	636·0	536·81
765·19	1·007	100·19	23·00	1308·85	66527·3	11·02	12·0794	636·8	536·61
765·23	1·007	100·19	23·03	1287·65	66526·2	11·26	11·9100	638·3	538·11
765·28	1·007	100·19	22·85	1275·57	66534·4	11·00	11·7908	637·9	577·71
765·20	1·007	100·19	21·63	1121·04	66526·2	11·27	10·3542	635·9	535·71
767·00	1·009	100·26	22·22	1274·57	66535·2	10·83	11·7613	635·9	535·64
767·03	1·009	100·26	22·38	1371·61	66526·7	11·14	12·6883	637·9	537·64
767·12	1·009	100·26	22·61	1369·23	66527·6	10·91	12·6666	637·9	537·64
767·02	1·009	100·26	20·92	1099·03	66533·4	11·23	10·1540	635·6	535·34
767·00	1·009	100·26	21·00	1120·99	66534·0	11·05	10·3599	635·8	535·54
767·09	1·009	100·26	23·81	1425·42	66526·2	11·29	13·1368	636·7	536·44
765·87	1·008	100·22	23·00	1425·58	66526·2	11·26	13·1702	637·6	536·38
765·72	1·008	100·22	21·45	1213·19	66535·0	10·88	11·2514	638·4	537·18
765·90	1·008	100·22	23·67	1376·68	66527·0	11·04	12·6904	636·8	536·58
765·92	1·008	100·22	22·00	1230·03	66534·9	10·90	11·3640	636·6	536·38
765·85	1·008	100·22	22·85	1321·87	66527·1	11·05	12·2085	637·2	536·98
770·10	1·013	100·37	18·79	1384·70	66545·8	6·03	12·8426	636·1	535·74
768·50	1·011	100·32	18·00	1266·75	66545·6	6·30	11·7818	636·7	536·38
768·47	1·011	100·32	19·37	1395·18	66538·5	6·51	12·9476	637·3	537·08
768·32	1·011	100·31	19·32	1354·70	66545·3	6·82	12·5640	636·1	535·79
766·19	1·008	100·22	16·03	1369·22	66544·2	4·13	12·7499	635·6	535·38
766·24	1·008	100·22	22·37	1956·04	66536·9	4·04	18·0644	636·9	536·68
767·15	1·009	100·26	18·36	1455·09	66544·9	4·64	13·5057	635·9	525·64
767·23	1·009	100·26	20·19	1612·69	66537·9	4·89	14·9242	635·9	535·64
735·76	0·968	99·09	18·89	1357·20	66545·6	5·67	12·5778	635·7	536·61
735·76	0·968	99·09	21·50	1772·29	66537·8	4·78	16·3707	636·1	537·01
735·09	0·967	99·07	18·02	1363·38	66545·6	5·64	12·6746	636·6	537·53
735·09	0·967	99·07	20·19	1575·64	66538·6	5·58	14·6091	636·9	537·83
742·87	0·977	99·36	18·16	1431·45	66543·3	3·77	13·2922	636·1	536·75
742·87	0·977	99·36	19·18	1619·65	66537·1	4·04	15·0354	636·8	537·46
742·08	0·976	99·33	16·86	1413·95	66544·2	4·12	13·1655	637·3	537·97
742·05	0·976	99·33	20·19	1691·20	66537·8	4·75	15·6584	636·4	537·07
740·53	0·974	99·27	19·03	1483·10	66545·0	4·81	13·7426	635·7	536·43
740·53	0·974	99·27	19·75	1590·50	66538·4	5·19	14·7505	636·8	537·53

NOTE.—Cent. × 1·8 + 32 = Fah.; Milemetre × ·03937 = inches; Grammes ÷ 453·544 = lbs. Heat conducted per minute = ·004° Cent.

Table, No. 50.

HEAT OF STEAM ABOVE ATMOSPHERIC PRESSURE.

STEAM.					WATER.			HEAT OF STEAM.		
Pressure.		Temperature.				Temperature.				
Milemetres of mercury.	Atmosphere of 14·706 lbs.	Before condensation. Deg. Cent.	After condensation. Deg. Cent.	Quantity condensed.	Quantity in condenser.	Before the admission of steam.	After the condensation of the steam.	Conducted to water per min.	Total quantity in steam.	Latent or diffused.
Mm.	Atm.	°	°	Grms.	Grms.	Cent.	Cent.	Cent.	Cent.	Cent.
1448·17	1·905	119·25	24·68	1456·27	66537·0	10·32	13·5190	0·00578	642·3	523·0
1462·73	1·924	119·60	19·72	1000·48	66536·9	10·37	9·3563	0·00578	641·8	522·2
1582·92	2·083	122·17	22·36	1253·75	66537·4	10·17	11·6780	0·00578	642·2	520·0
1742·81	2·293	125·2	18·12	1282·58	66545·8	6·07	12·0700	0·00600	643·9	518·7
1768·75	2·327	125·5	21·73	1669·45	66538·5	6·21	15·6032	0·00600	643·6	518·1
1849·26	2·433	127·2	18·16	1315·25	66545·8	5·94	12·3871	0·00600	644·8	517·6
1952·17	2·568	129·0	20·42	1517·46	66538·5	6·23	14·2464	0·00600	645·1	516·1
2285·26	3·007	134·4	25·27	1247·20	66527·1	12·35	11·6942	0·00600	649·0	514·6
2273·47	2·991	134·2	25·27	1262·70	66526·6	12·47	11·8112	0·00600	647·5	513·3
2335·18	3·072	135·1	24·83	1234·23	66523·0	12·82	11·5746	0·00600	648·5	513·4
2325·68	3·060	135·0	24·39	1238·80	66523·0	12·79	11·6347	0·00600	649·1	514·1
2340·83	3·080	135·2	23·96	1235·50	66525·2	12·60	11·5833	0·00600	647·6	512·4
2365·94	3·113	135·5	18·76	1376·53	66545·4	5·24	12·9977	0·00600	647·0	511·5
2370·32	3·119	135·7	19·42	1488·95	66538·5	5·40	14·0530	0·00600	647·3	511·6
2426·85	3·193	136·4	21·25	1641·90	66538·7	5·81	15·4585	0·00600	647·6	511·2
2498·63	3·288	137·5	17·59	1212·75	66545·7	6·11	11·4794	0·00600	647·4	509·9
2517·90	3·313	137·7	19·69	1407·72	66538·4	6·38	13·2781	0·00600	647·2	509·5
2588·05	3·394	138·6	16·84	1211·70	66545·6	5·50	11·5038	0·00600	648·4	509·8
2842·03	3·739	142·0	17·32	1287·05	66544·9	4·81	12·2258	0·00650	649·2	507·2
2860·71	3·764	142·2	17·29	1339·02	66537·1	4·10	12·7136	0·00650	648·9	506·7
2911·75	3·831	142·5	16·19	1184·84	66541·4	3·01	11·2475	0·00650	647·8	505·3
2955·66	3·889	143·4	17·92	1353·60	66537·9	4·85	12·8699	0·00650	650·3	506·9
3042·51	4·003	144·3	22·95	1221·20	66534·4	10·99	11·5008	0·00620	649·4	505·1
3049·85	4·013	144·3	18·74	1445·32	66538·5	5·40	13·7108	0·00650	649·7	505·4
3116·00	4·100	145·3	24·54	1246·50	66528·3	12·11	11·7345	0·00620	651·0	505·7
3128·00	4·116	145·4	25·12	1291·00	66528·0	12·22	12·1253	0·00620	649·9	504·5
3149·25	4·144	145·6	24·54	1307·01	66527·6	12·26	12·2711	0·00620	649·1	503·5
3223·09	4·241	146·5	21·79	1208·80	66537·8	10·90	11·4335	0·00620	651·1	504·6
3323·69	4·373	147·6	24·13	1305·50	66531·8	11·58	12·2756	0·00620	649·6	502·0
3437·85	4·523	149·0	24·12	1299·00	66533·0	11·27	12·2761	0·00620	652·8	503·8
3565·81	4·692	150·2	23·96	1296·48	66534·3	11·04	12·2523	0·00620	652·6	502·4
3883·14	5·109	153·5	15·59	1144·95	66537·5	4·67	10·9170	0·00670	650·1	496·6
3945·55	5·191	154·1	18·70	1499·90	66544·6	4·52	14·2327	0·00670	650·2	496·1
4045·13	5·335	155·1	15·84	1338·14	66542·5	3·42	12·7840	0·00700	651·3	496·2
4067·81	5·352	155·2	18·36	1402·45	66537·7	4·76	13·3174	0·00700	650·0	494·8
4068·44	5·353	155·2	18·59	1490·45	66537·3	4·65	14·1941	0·00700	652·0	496·8
4070·52	5·357	155·3	16·42	1313·88	66543·2	3·71	12·5336	0·00700	651·0	495·7
4115·06	5·415	155·7	17·32	1269·90	66544·5	4·37	12·1007	0·00700	651·4	495·7
4195·56	5·520	156·5	15·84	1360·26	66541·0	3·16	13·0276	0·00805	652·9	496·4
4268·10	5·616	157·1	18·16	1518·13	66542·0	3·36	14·4533	0·00805	651·4	494·3
4350·09	5·724	157·8	17·52	1491·04	66541·4	3·01	14·2382	0·00805	652·0	494·2
4643·15	6·109	160·3	16·71	1280·25	66544·5	4·43	12·2476	0·00810	653·1	492·8
4653·75	6·123	160·4	18·89	1509·65	66537·9	4·85	14·4008	0·00810	653·4	493·0
4821·20	6·344	161·8	14·77	1038·70	66537·5	4·45	9·9838	0·00830	654·1	492·3
5182·11	6·818	164·6	17·77	1292·20	66545·5	5·42	12·3514	0·00830	653·6	489·0
5212·47	6·858	164·9	19·65	1459·05	66538·6	5·73	13·9473	0·00830	655·4	490·5
6127·67	8·062	171·6	17·14	1390·60	66544·2	4·13	13·3434	0·00850	655·5	483·9

STEAM.					WATER.			HEAT OF STEAM.		
Pressure.		Temperature.				Temperature.				
Milemetres of mercury.	Atmosphere of 14·706 lbs.	Before condensation. Deg. Cent.	After condensation. Deg. Cent.	Quantity condensed.	Quantity in condenser.	Before the admission of steam.	After the condensation of the steam.	Conducted to water per min.	Total quantity in steam.	Latent or diffused.
Mm.	Atm.	°	°	Grms.	Grms.	Cent.	Cent.	Cent.	Cent.	Cent.
6287·61	8·273	172·6	19·07	1522·15	66537·5	4·52	14·5716	0·00850	655·8	483·2
6298·49	8·287	172·6	17·52	1190·38	66538·7	6·09	11·4135	0·00850	655·3	482·7
6329·21	8·328	172·8	17·20	1241·32	66545·7	5·69	11·9120	0·00850	655·6	482·8
6366·87	8·380	173·8	19·05	1530·15	66537·5	4·47	14·6566	0·00850	656·1	483·0
6401·76	8·423	173·4	17·20	1347·65	66544·1	4·10	12·9418	0·00850	656·0	482·6
6478·81	8·524	173·9	17·73	1449·30	66536·4	3·86	13·9066	0·00860	655·9	482·0
6483·35	8·530	174·0	17·60	1353·48	66543·9	4·00	12·9904	0·00900	656·0	482·0
6702·83	8·819	175·3	17·71	1347·95	66545·0	4·83	12·9349	0·00900	656·1	480·8
6728·59	8·853	175·5	19·57	1520·88	66538·2	5·06	14·5565	0·00900	656·1	480·6
7350·02	9·671	179·3	18·59	1457·30	66543·8	3·95	14·0992	0·00950	662·3	483·0
7416·65	9·759	179·6	18·59	1387·83	66544·6	4·60	13·4219	0·00950	662·2	482·6
7420·62	9·764	179·6	19·20	1471·35	66538·2	4·98	14·2353	0·00950	662·7	483·1
7465·28	9·822	180·0	20·00	1552·06	66537·7	4·67	14·9825	0·00950	662·2	482·2
8056·49	10·600	183·2	18·88	1337·88	66545·4	5·17	12·9428	0·00950	662·4	479·2
8106·48	10·666	183·5	20·77	1478·64	66538·6	6·15	14·2713	0·00950	662·8	479·3
8131·26	10·699	183·7	19·75	1413·98	66538·6	5·76	13·6712	0·00950	662·8	479·1
8138·24	10·708	183·7	20·92	1614·90	66545·4	5·17	15·5494	0·00950	661·8	478·1
8550·41	11·250	186·0	20·22	1465·93	66538·5	5·64	14·2028	0·01000	664·5	478·5
8563·30	11·267	186·0	20·42	1440·52	66545·4	5·08	13·9510	0·01000	664·9	478·9
8925·38	11·744	187·9	20·60	1537·38	66538·4	5·36	14·8716	0·01080	664·4	476·5
8990·73	11·830	188·2	19·75	1474·39	66544·9	4·75	14·3140	0·01080	665·6	477·4
9004·86	11·848	188·2	21·73	1617·02	66538·4	5·36	15·6185	0·01080	664·2	476·0
10141·52	12·344	193·8	21·66	1427·75	66545·5	6·61	13·8296	0·01100	666·0	472·2
10193·27	13·412	194·2	22·13	1479·00	66544·4	7·48	14·2716	0·01100	664·3	470·1
10332·38	13·595	194·7	23·33	1585·73	66538·4	6·50	16·2719	0·01100	665·4	470·7
10354·84	13·625	194·8	20·48	1456·67	66545·8	5·93	14·1389	0·01100	666·0	471·2

As an example of conversion into English definitions, the last experiment in the table gives—

10354·84	M.m. × ·03937 in.	=407·67 in. mer. as the press. of the steam.
13·625	Atm. × 14·706 lbs.	=200·37 lbs. avoir. as the press. of the steam.
194·8	Cent. × 1·8 + 32	=382-64 deg. Fah. temp. of the steam.
20·48	Cent. × 1·8 + 32	= 68·86 deg. Fah. temp. of condensed steam.
1456·67	Grms. ÷ 453·544	= 3·21 lbs. of steam condensed.
66545·8	Grms. ÷ 453·544	=146·72 lbs. of water in the condenser.
5·93	Cent. × 1·8 + 32	= 42·67 Fah. temp. of water before steam con.
14·1389	Cent. × 1·8 + 32	= 57·45 Fah. temp. of water after steam con.
·011	Cent. × 1·8	= ·0198 Fah. conv. to water in conden. per min.
·666	Cent. + 1·8 + 32	=1230·8 Fah. total heat of the steam.
471·2	Cent. × 1·8 + 32	=880·16 Fah. diffused heat of the steam.

Note.—2·205 lbs. av. = 1 kilogramme.
39.37 lbs. av. = 1 metre.

The following table contains a few examples of the total heat of steam.

TABLE, No. 51.

TOTAL HEAT IN STEAM BY FORMULA.

For French definitions, total heat = 606·5 + temp. × ·305.

For English definitions, total heat = 1123·7 + temp. − 32 × ·305.

These rules are readily applied. For example, the total heat of steam of 446° Fah. is 446° − 32 × ·305 + 1123·7 = 1249·97 Fah., and of course the diffused heat is 1249·97 − 446 = 803.97 Fah.

For French definitions the total heat of steam of 230 Cent. is 230 × ·305 + 606·5 = 676·65 Cent., and 676·62 − 230 = 446·65 Cent. as the diffused heat.

STEAM.						HEAT.	
Temperature.		Pressure.				Total.	
Cent.	Fah.	Milemetres of Mercury.	Inches of Mercury.	Atmos. of 14·706. lbs.	lbs. per sq. inch.	Cent.	Fah.
°	°	Mm.	In.	Atm.		°	°
0	32	4·60	0·1811	0·006	·088	606·5	1123·70
10	50	9·16	0·3606	0·012	·176	609·5	1129·10
20	68	17·39	0·6846	0·023	·338	612·6	1134·68
30	86	31·55	1·2421	0·042	·617	615·7	1140·16
40	104	54·91	2·1618	0·072	1·058	618·7	1145·66
50	122	91·98	3·6212	0·121	1·779	621·7	1151·06
60	140	148·79	5·8578	0·196	2·882	624·8	1156·64
70	158	233·09	9·1767	0·306	4·500	627·8	1162·04
80	176	354·64	13·9621	0·466	6·853	630·9	1167·62
90	194	525·45	20·6869	0·691	10·161	633·9	1173·02
100	212	760·00	29·9212	1·000	14·706	637·0	1178·60
110	230	1075·37	42·3374	1·415	20·809	640·0	1184·00
120	248	1491·28	58·7116	1·962	28·853	643·1	1189·58
130	266	2030·28	79·9321	2·671	39·279	646·1	1194·98
140	284	2717·63	106·9930	3·576	52·886	649·2	1200·56
150	302	3581·23	140·9930	4·712	69·294	652·2	1205·96
160	320	4651·62	183·1342	6·120	90·000	655·3	1211·54
170	338	5961·66	234·7105	7·844	115·35	658·3	1216·94
180	356	7546·39	297·1013	9·929	146·01	661·4	1222·52
190	374	9442·70	371·7590	12·425	182·72	664·4	1227·92
200	392	11688·96	460·1943	15·380	226·17	667·5	1233·50
210	410	14324·80	560·9673	18·848	271·17	670·5	1238·90
220	428	17390·36	684·6584	22·882	336·50	673·6	1244·48
230	446	20926·40	823·8723	27·535	404·93	676·6	1249·97

The weight or density of steam is that of the water it contains, but the force and weight increase in different ratios, as seen in the following table. At 62° Fah. a gallon of water weighs 10 lbs. and measures 277·274 cubic inches, and a cubic foot of water is 1728 ÷ 277·274 = 62·321 lbs. Since the relative volume of steam of 14·706 lbs. force and 212 Fah. is 1700, the weight of 1 cubic foot of steam is 62·321 ÷ 1700 = ·03666 lbs. nearly. See Tables, Nos. 57 and 60.

To find the weight of a cubic foot of steam of any other force, divide 62·321 by the relative volume due to the pressure.

Table, No. 52.

RELATIVE TEMPERATURE, FORCE, AND WEIGHT OF STEAM FROM OTHER EXPERIMENTS.

Temp. Fah.	Force in Atmospheres.	Force in lbs.	Weight in Atmospheres.	Weight in lbs. per cubic foot.	Ratio of weight to force, weight being 1.
32°	·006	·088	·00028		
212	1·	14·706	1·	·03666	1·
230	1·412	20·764	1·375	·0504	1·02682
248	1·951	28·691	1·852	·0678	1·05364
266	2·652	39·00	2·451	·0898	1·08046
284	3·529	51·897	3·187	·1168	1·10728
302	4·647	68·338	4·098	·1502	1·13410
320	6·026	88·618	5·191	·1903	1·16092
338	7·687	113·04	6·472	·2372	1·18744
356	9·692	142·53	7·980	·2925	1·21456
374	12·111	178·10	9·756	·3576	1·24138
392	14·947	219·81	11·786	·4320	1·26820
410	18·283	268·87	14·118	·51756	1·29502
428	22·136	325·53	16·746	·6139	1·32184
446	26·526	390·09	19·669	·7210	1·34868

In 1837, Mr. Josiah Parkes made 28 experiments, or an ordinary locomotive boiler, to test practically how far the theory of the sum of the heat in steam, being the same at all temperatures, was to be relied on. Considerable care was taken to obtain accurate results, as given in Table, No. 53.

Table, No. 53.

SUMMARY OF MR. PARKES'S EXPERIMENTS ON THE HEAT OF STEAM.

Expts.	Pressure.	Temp.	Coals.	Burnt.	Water.	Duration.	
No.	Above Atm. lbs.	Deg. Fah.	Total lbs.	Each ex. lbs.	Evapt. cub. ft.	h.	m.
4	0	212·	800	200	20	10	0
1	5	226·3	199	199	20	9	55
1	10	237·64	202	202	20	10	1
3	1	247·94	585	195	20	9	50
2	20	256·78	396	198	20	10	2
1	25	264·82	204	204	20	10	4
1	30	272·02	200	200	20	10	0
1	35	278·80	203	203	20	9	58
2	40	285·04	404	202	20	9	59
2	45	290·76	408	204	20	10	5
3	50	295·96	615	205	20	10	0
3	55	300·76	624	208	20	9	57
4	60	305·06	840	210	20	10	2

These really practical trials had evidently been conducted with great care, since they corroborate and confirm Regnault's more recent experiments—that the heat of steam increases with its pressure. However at the time Mr. Parkes himself drew the conclusion—that the heat of steam was constant at all pressures. The increase of coals required to evaporate the 20 cubic feet of water at the higher temperatures is obvious, but was attributed to the circumstances under which the trials were made. Had these experiments been as fairly dealt with as they had been carefully conducted, Mr. Parkes would have had the honour now claimed by M. Regnault, of submitting experimental proof of the increasing heat of steam.

These are a few of the leading expositions of steam which now engage attention; but other distinguished men—including Watt, Robinson, Southern, and Ure—have also given steam tables. Scarcely two of them correspond at any but the starting points; and, for reference, a number of them are comparatively arranged in the following tables.

Table, No. 54.

ELASTIC FORCE OF STEAM, BY VARIOUS AUTHORITIES, FROM − 22°, 22° TO 212° TEMPERATURE.

Temp.	Dalton.	Watt.	Robinson.	Southern.	Ure.	Tredgold.	Pambour.	Regnault.
Fah.	In. Mer.	In. Mer.	In. Mer.	In. Mer.	In. Mer.	In. Mer.	In. Mer.	In. Mer.
22	..	..	..	..	..	..	..	·013
4	..	..	..	..	..	..	..	·035
0	..	..	..	..	..	..	..	·081
14	..	..	..	..	..	..	..	..
24	..	..	..	..	·17	·118	..	..
32	·2	..	·0	·16	·2	·172	..	·18
40	·26	..	·1	..	·25	·245	..	..
42	·28	..	..	·23	..	·266	..	..
50	·37	..	·2	..	·36	·37	..	·36
52	·4	..	..	·35	..	·401	..	..
55	·44	·15	..	..	·416	·45	..	..
60	·52	..	·35	..	·516	·55	..	..
62	·56	..	..	·52	..	·587	..	..
68	..	..	..	..	..	..	..	·68
70	·72	..	·55	..	·72	·78	..	..
72	·77	·64	..	·73	..	·842	..	..
80	1·0	..	·82	..	1·01	1·106	..	1·03
82	1·07	·81	..	1·02	..	1·182	..	..
86	1·21	..	..	..	..	..	..	1·24
90	1·36	..	1·18	..	1·36	1·53	..	..
92	1·44	1·21	..	1·42	..	1·639	..	..
100	1·86	..	1·6	..	1·86	2·08	..	..
102	1·98	..	..	1·96	..	2·21	..	..
103	2·04	..	..	..	..	..	2·0	..
104	2·11	1·75	..	..	2·07	..	..	2·16
110	2·53	..	2·25	..	2·45	2·79	..	..
112	2·86	..	..	2·66	..	2·95	..	..
118	3·16	2·68	..	..	..	3·59	..	..
120	3·33	..	3	..	3·3	3·68	..	..
122	3·5	..	..	3·58	3·9	3·89	..	3·62
126	3·89	3·57	..	..	..	..	4	..
130	4·34	3·63	3·95	..	4·36	4·81	..	..
132	4·60	..	..	4·71	..	5·07	..	..
140	5·74	..	5·15	..	5·77	6·21	..	5·85
141	5·9	..	..	..	..	..	6	..
142	6·05	5·46	..	6·10	..	6·53	..	..
145	6·53	..	..	..	6·6	..	..	6·7
148	7·05	6·40	..	..	..	..	..	7·19
150	7·42	..	6·72	..	7·53	7·94	..	..
152	7·81	..	..	7.9	..	8·33	8	8·2
154	8·2	7·4	..	..	..	..	..	8·5

Temp.	Dalton.	Watt.	Robinson.	Southern.	Ure.	Tredgold.	Pambour.	Regnault.
Fah.	In. Mer.	In. Mer.	In. Mer.	In. Mer.	In. Mer.	In. Mer.	In. Mer.	In. Mer.
157	8·81	8·25	..	..	..	..	..	9·0
158	9·02	..	..	..	..	..	..	9·17
159	9·24	..	..	..	..	..	..	9·39
160	9·46	..	8·65	..	9·6	10·05	..	9·66
161·4	9·7	9.2	..	..	..	..	10	..
162	9·91	..	..	10·05	..	10·52	..	..
169·2	11·89	..	..	..	..	..	12	12
170	12·13	..	11·05	..	12·05	12·6	..	..
172	12·73	11·95	..	12·72	..	13·17	..	..
173	13·18	..	..	..	..	13·46	..	13·06
175	13·62	12·88	..	..	13·55	..	..	13·68
176	13·92	..	..	..	..	..	14	13·96
178	14·52	13·9	..	..	..	..	..	14·60
180	15·15	14·71	14·05	..	15·16	15·67	..	15·30
182	15·86	16 58	..	16·01	16.9	16·35	16	15·92
185	17·0	17·51	..	..	..	..	..	17·09
187	17·8	..	..	..	..	..	18	17·88
190	19·0	..	17·85	..	19	19·35	..	19·29
192·4	20·01	..	..	..	..	..	20	..
194	20·77	..	..	..	21·06	..	..	20·68
197	22·13	21·37	..	..	..	..	22	..
200	23·64	..	22·62	..	23.6	23·71	..	..
201·3	24·24	..	..	..	..	..	24	..
205·3	26·29	..	..	..	26·1	..	26	..
209	28·29	..	..	..	..	..	28	..
212	30	30	30	30	30	30	29·92	29·92

Table, No. 55.

ELASTIC FORCE OF STEAM, BY VARIOUS AUTHORITIES, FROM 212° TO 320°.

Temp.	Taylor.	Ure.	Tredgold.	Franklin Institute.	French Academy.	Pambour.	Regnault.
Fah.	In. Mer.	In. Mer.	In. Mer.	In. Mer.	In. Mer.	In. Mer.	In. Mer.
212	30	30	30	30	29·92	29·92	29·92
216·4	32·6	33·4	..	..	..	32	..
220	35	35·54	34·92	..	..	34·2	..
222·6	36·64	..	..	..	..	36	..
225	38	39·11	38·32	..	..	..	..
225·6	38·4	39·55	..	..	..	38	..
228·3	40·4	41·50	..	..	..	40	..

Temp.	Taylor.	Ure.	Tredgold.	Franklin Institute.	French Academy.	Pambour.	Regnault.
Fah.	In. mer.	In. mer.	In. mer.	In. mer.	In. mer.	In. mer.	In. mer.
230·	41·55	43·10	42·	..	..	..	42·27
231·	42·25	43·9	..	..	..	42·	..
233·6	44·25	..	..	..	..	44·	..
234·	44·6	46·4	..	43·05	45·	..	..
235·	45·5	47·22	..	45·	..	..	..
236·4	46·49	..	..	..	..	46·	..
238·4	48·56	50·28	..	..	..	48·	..
239·25	49·35	..	..	47·34	..	..	..
240·	50·	51·7	50·24	..	..	..	..
240·7	50·62	..	..	..	..	50·	..
243·	52·62	..	..	..	..	52·	..
245·1	54·49	56·38	..	52·1	..	54·	..
246·5	55·16	..	..	..	..	..	57·15
247·2	56·44	..	..	..	..	56·	57·7
248·	57·20	59·9	..	..	..	..	58·61
249·2	58·40	..	..	..	..	58·	..
250·	59·12	61·9	59·79	60·	..	..	..
250·5	59·62	..	..	..	60·	..	..
251·	60·10	..	..	..	..	60·	..
252·	61·12	..	..	..	..	..	63·
253·1	62·31	..	..	..	..	62·	..
255·	64·4	67·25	..	..	..	64·	..
256·25	65·73	..	..	65·37	..	..	..
256·8	66·4	..	..	..	..	66·	..
257·36	67·1	69·70	..	..	..	..	68·79
258·6	68·45	..	..	..	..	68·	..
260·	70·12	72·3	..	70·8	..	..	..
260·3	70·45	72·7	..	..	..	70·	..
260·96	..	..	..	..	..	..	72·99
261·	71·25	..	72·	..	..	..	..
262·	72·45	74·9	..	72·9	..	72·	..
263·8	74·45	..	..	..	75·	74·	..
264·	74·8	..	..	75·	..	..	77·
265·3	76·38	78·40	..	..	..	76·	..
266·	77·25	..	..	..	..	..	79·88
266·9	78·38	81·89	..	..	..	78·	..
268·4	80·33	..	..	..	..	80·	..
270·5	82·5	86·3	83·45	81·	..	82·	..
271·	83·9	..	..	82·56	..	..	..
271·4	84·4	88·17	..	..	..	84·	..
272·	85·45	..	86·2	..	..	..	..
273·	86·95	90·71	..	..	..	86·	89·2
274·	88·5	..	..	..	..	..	90·33
275·	90·	93·48	..	90·	90·	88·7	91·8
275·7	91·05	94·6	..	..	..	90·	..

Temp.	Taylor.	Ure.	Tredgold.	Franklin Institute.	French Academy.	Pambour.	Regnault.
Fah.	In. mer.	In. mer.	In. mer.	In. mer.	In. mer.	In. mer.	In. mer.
276·26	92·0	..	..	..	..	..	93·57
277·1	93·3	97·01	..	..	92·	92·	95·2
278·4	95·3	..	..	94·41	..	94·	..
279·7	97·2	101·8	..	..	..	96·	98·9
280·	97·75	101·9	97·92	..	..	..	..
281·	99·25	..	..	..	..	98·	..
282·	100·7	104·68	..	..	..	..	102·12
282·3	101·15	..	..	..	..	100·	..
283·6	103·1	107·98	..	..	..	102·	..
284·	103·8	..	..	105·	..	102·8	106·71
284·8	104·4	..	..	109·65	110·8	104·	..
286·	107·3	..	..	112·62	..	106·	..
287·2	109·14	114·8	..	..	..	108·	111·95
288·5	111·7	..	..	..	..	110·18	114·93
290·7	116·	120·15	115·6	119·75	..	114·	..
291·9	118·1	..	..	..	..	116·	120·76
293·	120·25	..	..	121·5	..	118·	..
293·72	121·68	..	120·93	..	126·	..	123·48
294·1	122·40	126·9	..	128·11	..	120·	..
295·	124·15	129·	123·5	..	..	122·2	127·22
295·9	125·85	130·9	..	131·21	..	124·	..
297·	128·	133·7	..	..	..	126·	..
297·68	122·2	..	..	..	..	..	131·19
298·5	130·7	137·0	..	135·8	..	128·7	..
299·1	131·8	..	..	141·9	..	130·	..
300·	133·75	139·7	133·2	142·6	..	131·82	135·51
302·	137·55	144·3	..	144·33	..	135·6	140·6
303·5	140·82	147·1	..	146·72	..	138·6	..
304·2	142·3	..	..	150·3	..	140·	..
305·5	145·12	151·16	..	154·28	..	142·78	..
308·	150·65	157·7	..	..	151·07	148·	152·97
310·	155·	161·3	154·5	165·	..	152·2	157.23
311·7	157·	166·32	..	..	..	156·	160·86
312·6	160·83	..	160·3	..	..	158·	162·45
314·0	164·20	..	..	..	164·8	161·8	166·27
314·75	166·1	..	..	181·23	..	..	168·48
316·04	169·15	..	..	..	..	166·	171·7
317·8	173·78	..	..	186·36	..	170·	..
319·75	178·98	..	..	197·13	179.25	174·84	174·87
320·75	181.6	..	..	193·92	..	..	183·70

NOTE.—The French Academy pressure has been rendered by taking each atmosphere as equal to 30 in. mer.

Table, No. 56.

ELASTIC FORCE OF STEAM BY VARIOUS AUTHORITIES, FROM 321° TO 510° TEMPERATURE.

Temperature.	Franklin Inst.	French Aca.	Pambour.	Regnault.
Fah.	In. mer.	In. mer.	In. mer.	In. mer.
321·	195·	..	178·	..
323·24	..	..	183·5	190·32
326·26	210·5	195	191·5	..
327·75	219·14	..	194·9	..
328·28	..	..	196·5	204·54
329·75	232·62	..	200·2	..
331·7	..	210	..	..
333·2	..	..	210	..
334·5	240·48	..	..	..
336·86	..	225	..	..
338·75	248·92	..	..	239
340·	255·	..	..	..
340·5	257·5	..	..	..
340·88	258·16	..	..	241·86
341 78	..	240	..	..
342·68	..	..	..	248·19
343·3	..	..	240	249·12
343·58	..	..	..	251·44
343·6	..	..	..	252·69
344·12	..	..	..	252·69
345·02	267·6	..	..	255·72
348·	278·33	..	..	265·9
349·	285·	..	..	..
350·	290·35	..	..	..
350·78	..	270	..	..
352·	297·36	..	..	..
352·4	300·	..	270	..
354·74	..	..	..	290·13
355·28	..	..	..	292·92
356·	..	..	..	294·66
358·8	..	300	..	..
360·8	..	..	300	..
361·76	..	..	..	319·98
361·23	..	..	..	320·97
366·8	..	330	..	338·01
368·5	..	..	330	..
370·56	..	..	..	354·9
374·	..	360	..	371·18
375·6	..	..	360	..
380·66	..	390	..	..
380·84	..	..	..	400·32

Temperature.	Franklin Inst.	French Aca.	Pambour.	Regnault.
Fah.	In. mer.	In. mer.	In. mer.	In. mer.
381·56	..	..	..	402·36
382·3	..	..	390	..
382·64	..	..	..	408·75
386·94	..	420	..	..
388·6	..	..	420	..
392·86	..	450	..	460·19
394·6	..	..	450	..
398·48	..	480	..	..
400·2	..	..	480	..
403·82	..	510	..	..
408·92	..	540	..	..
410·	..	...	..	563·3
413·78	..	570	..	..
418·46	..	600	..	..
423·	..	630	..	..
427·28	..	660	..	..
429·	..	678	..	..
431·4	..	690	..	..
435·5	..	720	..	..
439·3	..	750	..	..
446·	..	824	..	..
457·16	..	900	..	..
472·73	..	1050	..	..
486·59	..	1200	..	..
499·136	..	1350	..	..
510·6	..	1500	..	..

It is seen above that, at a temperature of 510·6°, water as steam acquires an elastic force equal to the pressure of a column of mercury 1500 inches high. Its elastic power is the source of its danger, for it would expand to fill about 340 times its original space at atmospheric pressure. Suddenly released, as in boiler explosions, its elasticity gives it a gunpowder-like force, and the fracture gives a gun-like direction to its recoil. Water of the same pressure in a hydraulic press would only expand about $\frac{1}{400}$th part of its volume, or $\frac{1}{20000}$th part of its volume per atmosphere of pressure.

Laws of Steam.

This summary of the experimental researches into the properties of steam shows, as might reasonably be expected, that there are different values placed upon the force of steam of a given temperature. These differences have led to various laws or formulæ being submitted, whereby to find the force from the temperature, or *vice versâ,* both by the experimenters and by others, such as Biot, Hann, Tate, and Rankine, who have reviewed their experimental labours.

At best these laws only give approximations to practical results, but as they are useful in calculating the theoretical values of steam, a few of the principal ones will be given. They are all based on the same general plan, only varying in their constants and co-efficients. Many of them involve so complex quantities to be raised to the fifth or sixth powers, or to have their fifth or sixth root extracted, that, arithmetically, they are rarely attempted to be solved. By logarithms, however, their solution is comparatively easy, as will be shown by an example.

To find the pressure of steam from its temperature, and the temperature from its pressure.

RULES OR FORMULÆ BY DIFFERENT AUTHORITIES.

For pressures from zero up to 48 inches of mercury.

Southern:—

$$\text{Press.} = {\cdot}04948 + \left(\frac{51{\cdot}3 + \text{temp.}}{155{\cdot}7256}\right)^{5{\cdot}13} \text{ for ins. of mercury.}$$

$$\text{Log pr.} = 5{\cdot}13 \text{ log.} ({\cdot}0064216 \text{ temp.} + {\cdot}329426) \text{ for lbs. per sq. in.}$$

$$\text{Temp.} = (155{\cdot}7256 \text{ press.} - 04948)^{\frac{1}{5{\cdot}13}} - 51{\cdot}3.$$

$$\text{Log temp.} = \text{log.} (\text{press.} - 04948)^{\frac{1}{5{\cdot}13}} + \text{log. } 155{\cdot}7256 - 51{\cdot}3.$$

Pressures from 10 to 120 inches of mercury.

Tredgold:—

$$\text{Press.} = \frac{\text{temp.} + 100^6}{177} \text{ for ins. of mercury.}$$

$$\text{Log pr.} = 6 \text{ log.} (\text{temp.} + 100) - 2{\cdot}247973 \text{ for ins. of mercury.}$$

Temp. = 177 press. $^{\frac{1}{6}}$ − 100.

Log temp. = log. (press. 2·247973) − 100.

Mellet :—

$$\text{Press.} = \frac{\text{temp} + 103^6}{201{\cdot}18.}$$

Log press. = 6 log. (·0049707 temp. + ·511979)^5.

Temp. = 201·18 press. $^{\frac{1}{6}}$ − 103.

Log temp. = log. (201·18 + log. press. $^{\frac{1}{6}}$ − 103.

For pressures from 60 lbs. to 360 lbs. per square inch.

French Academy :—

Log press. = 5 log. (·00680309 temp. + ·26974).

Press. = (·00680309 temp. + ·26974)^5.

Temp. = 146·992, pressure $^{\frac{1}{5}}$ − 39·6436.

Log temp. = log. (press. $^{\frac{1}{5}}$ + log. 146·992) − 39·6436.

Pambour :—

$$\text{Press.} = \left(\frac{98{\cdot}806 + \text{temp.}^6}{198{\cdot}562}\right)$$

Log press. = 6 log. (·0050362 temp. + 497608).

Temp. = 198·562 press.$^{\frac{1}{6}}$ — 98·806.

Log temp. = log. (198·562 + log. press.$^{\frac{1}{6}}$) — 98·806.

Franklin Institute :—

Press = (·00333 temp. + 1)^6 = atmospheres of 30 in. mer.

Log press. = 6 log. (·00333 + 1).

$$\text{Temp.} = \frac{\text{pressure}^{\frac{1}{6}} - 1}{{\cdot}00833}.$$

By log. = log. (press. −) — ·00333.

By substituting the respective exponents for each formula one or two given in words at length will apply to the others.

Taking that of the Franklin Institute, as one of the simplest form, adapted to recent experiments, it may be thus expressed :—

Rule.—Multiply the excess of the temperature above 212° by ·00333, and add 1 to the product. This sum raised to the 6th power gives the pressures in atmospheres.

Example.—Required the pressure of steam whose temperature is 302°.

$302-212=90°$ above atmospheric pressure.
and $90 \times \cdot 00333+1=1 \cdot 2997$

	1·2997
	1·2997
	90979
	116973
	116973
	25994
	12997
2nd power =	1·68922009
	1·2997
	1182454063
	1520298081
	1520298081
	337844018
	168922009
3rd power =	2·195479350973
	1·2997
	15368355456811
	19759314158757
	19759314158757
	4390958701946
	2195479350973
4th power =	2·8534645124596081
	1·2997
	19974251587217256 7
	256811806121364729
	256811806121364729
	57069290249192162
	28534645124596081
5th power =	3·708647826843752647 57
	1·2997
	25960534787906268532 99
	33377830441593773828 13
	33377830441593773828 13
	74172956536875052951 4
	37086478268437526475 7
6th power =	4·8201295805488523160467 29 = 4·82 atmosph.

and $4 \cdot 82 \times 14 \cdot 75=71 \cdot 09$ lbs. per square inch, as the pressure by this rule.

By arithmetic, as this example indicates, the application of these rules is not very inviting, but by logarithms it is comparatively easy, hence their great advantage for such calculations.

By logarithms the rule is—Multiply the excess of the temperature above 212° by ·00333, and add 1 to the product. The logarithm of the sum, multiplied by 6, gives a logarithm whose natural number indicates the pressure in atmospheres.

Taking the same example, we have—

$$302° - 212° = 90 \times \cdot 00333 + 1 = 1 \cdot 2997,$$

$$\text{and log. of } 1 \cdot 2997 = 0 \cdot 113843 \times 6 = \cdot 683058,$$

and the natural number of ·683058 = 4·82 atmospheres as before.

For the French Academy formula multiply the temperature by ·00680309, and add ·26974 to the product, which sum raised to the fifth power gives the pressure in lbs. per square inch, and in like manner for the others, by substituting the respective exponents for those given in this example.

By logarithms it is—Multiply the temperature by ·0068309, and add ·26974 to the product. Multiply the logarithm of this sum by 5 for a logarithm, whose natural number gives the pressure in lbs. per square inch.

It will be unnecessary to weary the reader with another arithmetical solution more extensive than the last, when a logarithmetical one is preferable. Taking the last example, by this rule we have

$\cdot 0068309 \times 302°$ (temp.) $+ 26974 = 2 \cdot 32427$, whose log. $= 0 \cdot 36629 \times 5 = 1 \cdot 83145$, and the natural number of $1 \cdot 83145 = 66 \cdot 55$ lbs. per square inch for the equivalent pressure by this rule, or 4·54 lbs. per inch less than the formula of the Franklin Institute.

Franklin Institute formula.—From the sixth root of the pressure in atmospheres subtract 1, and divide the remainder by ·00333 for the temperature above 212°.

By logarithms.—Divide the logarithm of the pressure in

atmospheres by 6, and from the natural number of the remainder deduct 1. From the logarithm of this last remainder subtract the logarithm of ·00333, for a logarithm whose natural number gives the excess of temperature above 212°.*

Example.—Required the temperature of steam whose pressure is 4·82 atmospheres.

By logarithms, we have

$$\text{log. of } 4{\cdot}82 = \frac{0{\cdot}683047}{6} = 0{\cdot}113841, \text{ whose natural number}$$
$$= 1{\cdot}2996 - 1 = {\cdot}2996, \text{ and}$$

$$\begin{aligned}\text{log. of } {\cdot}2996 &= {\cdot}476542\\ \text{log. of } {\cdot}00333 &= \bar{2}{\cdot}522444\\ \hline \text{nat. num. of } 3{\cdot}954098 &= 89{\cdot}97° \text{ temperature,}\end{aligned}$$

which added to 212 = 301·97°, or within ·03 of a degree of the temperature given in the first example.

French Academy.—Multiply the 5th root of the pressure in lbs. per square inch by 146·992, and from this product deduct 39·6436, the remainder will give the temperature in deg. of Fah.

Or by logarithms.—To one fifth of the logarithm of the pressure add the logarithm of 146·992, or (2·1672937), and from the natural number of the logarithm of this sum deduct 39·6436 for the temperature in deg. of Fah.

Example.—Required the temperature of the steam whose pressure is 66·55 lbs. per square inch.

By logarithms:

$$\begin{aligned}\text{log. of } 66{\cdot}55 &= \frac{1{\cdot}823148}{5} = 0{\cdot}3646296\\ \text{add log. of } 146{\cdot}992 &= \qquad\quad = 2{\cdot}1672937\\ \hline \text{and natural number of } &\quad 2{\cdot}5319233 = 340{\cdot}9\end{aligned}$$

* See Law's Rudimentary Logarithms.

and $340 \cdot 9 - 39 \cdot 6436 = 301 \cdot 256°$ temp., or only ·74 less than the temperature given to find the pressure of 66·55 lbs.

TO FIND THE TOTAL HEAT DIFFUSED IN STEAM FROM THE TEMPERATURE.

Rule for Regnault's experiments:—

Total heat = 305 temp. + 606·5 for deg. Cent.

" = 305 (temp. − 32) + 1123·7 for deg. Fah.

Example.—Required the total heat of steam whose thermometeric heat is 212° Fah., or 100° Cent.

For Fah. $212 - 32 \times \cdot 305 = 54 \cdot 9$, and

$54 \cdot 9 + 1123 \cdot 7 = 1178 \cdot 4°$

For Cent. $100 \times \cdot 305 + 606 \cdot 5 = 637°$ Cent.

TO FIND THE DIFFUSED HEAT FROM THE TEMPERATURE.

Diffused heat = 305 temp. + 506·5 for deg. Cent.

" = 305 (temp. − 32) + 911·7 for deg. Fah.

Example.—Required the diffused heat of steam whose temperature is 320° Fah. or 160° Cent.

For Fah. $320° - 32 \times 305° + 911 \cdot 7 = 999 \cdot 54°$

For Cent. $160 \times 305 + 506 \cdot 5 = 555 \cdot 3$ Cent.

EXPANSIVE FORCE OF STEAM AND OTHER ELASTIC FLUIDS.

The expansive force of steam is now extensively employed, and greatly contributes to the economy of the modern steam engine. It is usual to estimate this force by the laws of air as defined by Boyle and Mariotte. These laws are simple and may be thus expressed:—

The pressure or force of a confined elastic body is in the ratio of the space in which it is confined, hence the contents of any given space containing an elastic fluid, multiplied by the pressure of that fluid, will be a constant quantity of force, and its pressure in any other space will be that constant quantity, divided by the contents of the space into which the fluid has entered; or its force is inversely as its space.

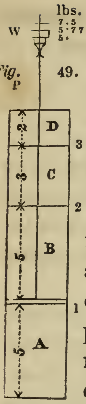


Fig. 49.

For example, let the fig. No. 49 represent a cylinder 15 inches long and one square inch area, fitted with a piston P, and the part A, 5 inches long, filled with steam or air of 15 lbs. pressure, and the space B C D a vacuum. Now, if the weight or resistance W, on the piston rod, balance the 15 lbs., the piston will be stationary at 1; but if a weight of 7·5 lbs. is removed, the balance will be destroyed, and the piston ascend by the expanding force of the confined steam or air in A, until a balance of pressure again takes place. Suppose this is at 2, the piston will have moved 5 inches, and the steam or air will occupy double the space it did in A, with only half its original pressure, for the original pressure 15×5 in. space $= 75$ for the constant quantity, and $75 \div$ by the space A B $= 10$ ins. gives 7·5 lbs. as the expansive force in A B.

If another weight is removed of 5·77 lbs., the expanding air or steam will again raise the piston as before; and if it become stationary at 3, the space A B C will be equal to 13, and the constant quantity $75 \div 13 = 5{\cdot}77$ lbs. is the pressure exerted in the space A B C. If the last weight is removed, the expanding air will raise the piston to the top and occupy a space of 15 inches, or three times its original space, still giving out a force $= 75 \div 15 = 5$ lbs. per square inch.

These results may be thus stated :—

The space A B : the space A : : the force in A : the pressure A B;
for 10 : 5 : : 15 : 7·5, the pressure in A B = 1st expansion.

The space A B C : the space A B : : the force in A : the pressure A B C;
for 13 : 5 : : 15 : 5·77, the pressure in A B C = 2nd expansion.

The space A B C D : the space A B C : : the force in A : the force in A B C D;
for 15 : 5 : : 15 : 5, the pressure in A B C D = 3rd expansion.

Compression is the converse of expansion, and the pressure would be in the ratio of the compressing force.

Thus to compress the air into its original space of 5 inches again, we have $15 \times 5 = 75$ as the constant quantity, and

$75 \div 13 = 5{\cdot}77$ lbs. = 1st compressing force.
$75 \div 10 = 7{\cdot}5$ lbs. = 2nd compressing force.
$75 \div 5 = 15{\cdot}$ lbs. = 3rd compressing force.

This example of elasticity will show that the pressure or force in the original space, is to the force in the other spaces, as the contents of each of these spaces are to the contents of the original space, and explains the general law of air, as applied to ordinary steam.

The theoretical line C G, which diagrametically represents the ratio of expanding pressure is found to be a hyperbolic curve, as shown in Fig. No. 50, which represents a cylinder of 12 square inches area and 24 inches long, divided into 24 equal parts.

Ex. Let each line of division, 1, 2, 3, 4, &c., represent the position of a piston impelled by air or steam, having a pressure of 100 lbs. per sq. inch, and cut off at one-quarter stroke; required, the mean pressure throughout the stroke, the mean pressure throughout the expansive portion of the stroke, and the pressure at each separate ordinate of division during the expansive action.

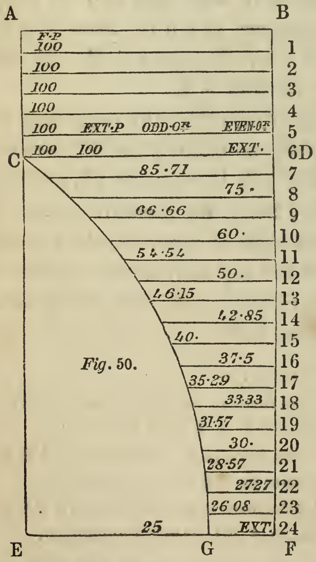


Fig. 50.

Full press. = 600
Extreme press. = 125
Odd ordinate press. = 414·57
Even „ „ = 355·95

The rectangular part of full pressure A B C D × by the hyperbolic logarithm of the ratio (4) of expansion

being = to the area of the rectangular hyperbola C D G F, we have for the mean pressure throughout the stroke,

Hyp. log. of 4 = 1·386 × 6 (full pressure part) = 8·316 as the area of the space C D E F, which multiplied by the pressure 100 = 831·6, and ÷ 18 (the number of the spaces) = 46·2 lbs. per square inch as the mean pressure of expansion; and throughout the cylinder the full pressure = 6 parts × 100 (pressure) = 600 + 831·6 (expansive pressure) = 1431·6 ÷ 24 spaces = 59·65 lbs. as the mean pressure throughout the stroke.

The mean pressure throughout the cylinder may be found more readily by considering the full pressure part as 1, or the unit of the ratio of expansion, and adding it to the hyp. log. of the ratio. This sum, multiplied by the pressure and divided by the ratio of expansion, will give the mean pressure. Thus hyp. log. of 4 = 1·386 + 1 = 2·386 × 100 ÷ 4 = 59·65 lbs. as before.

If instead of multiplying by the pressure and dividing by the ratio of expansion, the sum 2·386 is multiplied by the extreme pressure of 25 lbs. or 100 ÷ 4 = 25, it is obvious that the result will be the same.

Table, No. 59, contains Napierian (often called hyperbolic) logarithms for calculating expansive steam power, as in this example.—See Page 215.

The base of the Napierian logarithms, still used in the highest branches of mathematical analysis, is 2·71828, whose asymptotes are at right angles to each other; but the base of the Briggean logarithms, used in all ordinary calculations, is 10, whose asymptotes make an angle of 25·7404° to each other.

For the pressure at each ordinate of expansion: By the law of expansion we have 6 × 100 for the constant quantity expanding to fill from 6 to 24 successively increasing spaces, hence—

Full pressure 6 spaces × 100÷6 = 100 lbs. mean pressure, and for expansion,

As 7 spaces	: 6 spaces	:: 100 lbs. press.	: 85·71 lbs. press. at	1st exp. ord.
8 ,,	: 6 ,,	:: 100 lbs. ,,	: 75· ,,	2nd ,,
9 ,,	: 6 ,,	:: 100 lbs. ,,	: 66·66 ,,	3rd ,,
10 ,,	: 6 ,,	:: 100 lbs. ,,	: 60· ,,	4th ,,
11 ,,	: 6 ,,	:: 100 lbs. ,,	: 54·54 ,,	5th ,,
12 ,,	: 6 ,,	:: 100 lbs. ,,	: 50· ,,	6th ,,
13 ,,	: 6 ,,	:: 100 lbs. ,,	: 46·15 ,,	7th ,,
14 ,,	: 6 ,,	:: 100 lbs. ,,	: 42·85 ,,	8th ,,
15 ,,	: 6 ,,	:: 100 lbs. ,,	: 40· ,,	9th ,,
16 ,,	: 6 ,,	:: 100 lbs. ,,	: 37·5 ,,	10th ,,
17 ,,	: 6 ,,	:: 100 lbs. ,,	: 35·29 ,,	11th ,,
18 ,,	: 6 ,,	:: 100 lbs. ,,	: 33·33 ,,	12th ,,
19 ,,	: 6 ,,	:: 100 lbs. ,,	: 31·57 ,,	13th ,,
20 ,,	: 6 ,,	:: 100 lbs. ,,	: 30· ,,	14th ,,
21 ,,	: 6 ,,	:: 100 lbs. ,,	: 28·57 ,,	15th ,,
22 ,,	: 6 ,,	:: 100 lbs. ,,	: 27·27 ,,	16th ,,
23 ,,	: 6 ,,	:: 100 lbs. ,,	: 26·08 ,,	17th ,,
24 ,,	: 6 ,,	:: 100 lbs. ,,	: 25· ,,	11th ,,

Exp. 18 spaces and 795·92 ÷ 18 = 44·2 lbs. as the arithmetical mean of expansive pressure.

These values give the pressure at each separate line of expansion, yet the arithmetical mean only represents the mean of rectangular spaces, but does not include the curved portion at the end of each rectangle, and gives a mean 2 lbs. less than the real mean found by hyp. logarithms. The full pressure being the same in both cases, the mean difference is less than the expansive difference, for 600 × 795·92 ÷ 24 = 58·14 lbs. as the mean arithmetical pressure throughout the cylinder, or 1·51 lb. less than the real mean.

The contrary would take place with compressed steam, as each rectangle would contain a space beyond the curved line, and thus give the pressure in excess. A near approximation is obtained by adding together the two extreme pressures;

4 times the sum of the *even* ordinates (8, 10, 12, etc.), and twice the sum of the *odd* ordinates (7, 6, 11, etc.). This sum multiplied by the common distance, and divided by 3, gives the force of expansion nearly; thus referring to the diagram, No. 50.

The extreme pressures	= 100·	+ 25 =	125·
The even ordinates	= 355·95 ×	4 =	1423·8
The odd ordinates	= 414·37 ×	2 =	829.14

$$\frac{2377{\cdot}94}{3} = 792{\cdot}65 \text{ lbs.}$$

as the amount of the expansive pressure, and $\frac{792{\cdot}65 + 600}{24} =$ 58·02 lbs., or 1·63 less than by hyp. logarithms.

A summary of these methods of calculation will show their comparative approximation.

Hyperbolic	method	= 59·65 lbs.
Ordinate	„	= 58·02 „
Arithmetical	„	= 58·14 „

Either method may therefore be used, according to the degree of accuracy required, for with working steam the effect of losing temperature, or of condensation, would cause the result to be less than the hyperbolic mean.

Double Cylinder Expansion.

This plan of working stationary engines with high-pressure steam in a small cylinder, and then expanding it to work another piston in a larger cylinder communicating with a condenser, is now found to be a very useful one.

It is on this plan that Mr. Adams proposes his cylinders for locomotive engines.

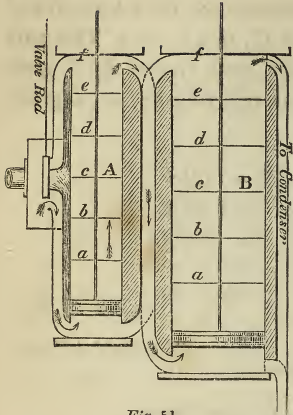


Fig. 51.

Let fig. No. 51 represent two such cylinders, of which the smaller, A, is 6 cubic feet in capacity, and the larger, B, of 24 cubic feet capacity, or in the ratio of 1 to 4. The first cylinder, A, receives the steam, say of 40 lbs. pressure per square inch from the boiler, and the second cylinder, B, receives the steam, as indicated by the respective arrows, from the cylinder A, after it has done its duty in that cylinder. Now, as the area of the larger cylinder is 4 times that of the smaller one, it follows that the steam expands to 4 times its volume in the larger cylinder, with a power corresponding to the diminution of force, and whilst the communication between the two cylinders is open, there is the same pressure in both cylinders, consequently the effective pressure in the larger cylinder is only on the three-fourths of its area, which it exceeds the smaller one.

As has been seen, the pressure of elastic fluids is inversely as the space they occupy; if we suppose these cylinders divided into, say six equal parts, 1, 2, 3, 4, 5, 6, it will sufficiently illustrate the comparative force of two cylinders.

For a constant quantity we have the capacity of the smaller cylinder, as 6 cubic feet, to be expanded into 24 cubic feet, and also fill the passages, say $\frac{6}{10}$ of a foot, between the cylinders. If the pistons be moved through one-sixth of their stroke to *a a*, the pressure would be as under:

IN SMALL CYLINDER.						IN LARGE CYLINDER.				
Full pres.		Empty space.		Space still filled.		Space filled.		Passages.		Steam expanded to fill.
c. ft.		c. ft.		c. ft.		c. ft.		c. ft.		c. ft.
6	—	0	=	0	+	0	+	·0	=	6· initial
6	—	1	=	5	+	4	+	·6	=	9·6 for *a a*
6	—	2	=	4	+	8	+	·6	=	12·6 for *b b*
6	—	3	=	3	+	12	+	·6	=	15·6 for *c c*
6	—	4	=	2	+	16	+	·6	=	18·6 for *d d*
6	—	5	=	1	+	20	+	·6	=	21·6 for *e e*
6	—	6	=	0	+	24	+	·0	=	24·6 for *f f*

Taking the force of steam as 40 lbs. per square inch, the pressures for the respective ordinates of expansion, in double and single cylinder engines, would then be inversely—

	Expand. space.		lbs.		Orig. space.		In dble. cylin. lbs.	Expanded space.	In single cylin. lbs.
Initial in first cylin.	6	:	40	::	6	:	40·	none	40·
Initial in second cyl.	6·6	:	40	::	6	:	36·36	between the pistons	none
First space of expan.	9·6	:	40	::	6	:	25·	ditto, or *a a*	26·26
Second ,,	12·6	:	40	::	6	:	19·04	ditto, or *b b*	20·
Third ,,	15·6	:	40	::	6	:	15·38	ditto, or *c c*	16·
Fourth ,,	18·6	:	40	::	6	:	12·36	ditto, or *d d*	13·33
Fifth ,,	21·6	:	40	::	6	:	11·11	ditto, or *e e*	11·42
Sixth ,,	24·6	:	40	::	6	:	9·75	ditto, or *f f*	10·

The mean pressure may be found by the rules already submitted. For the large cylinder by hyp. log. it will be

Exponent of expansion $= 24{\cdot}6 \div 6 = 4{\cdot}1$, whose log. $= 1.411 \times 36{\cdot}36 \times 6{\cdot}6 \div 18{\cdot}6$ (spaces to fill) $= 18{\cdot}2$ lbs., nearly as the mean pressure throughout the stroke on the large piston. On the smaller piston it would be $40 - 18{\cdot}2$ (the pressure on the larger piston) $= 21{\cdot}8$ lbs., hence taking the value of the vacuum in the condenser as = to 12 lbs., for the power exerted we have the

$$\left.\begin{array}{lll}\text{Small cylinder area} & = 6 \times 21{\cdot}8 & = 120{\cdot}8 \\ \text{Large cylinder area} & = 24 \times 18{\cdot}3 & = 436{\cdot}8 \\ \text{Condenser vacuum} & = 24 \times 12{\cdot}0 & = 288\end{array}\right\} \div 24 = 35{\cdot}23 \text{ lbs. mean pressure.}$$

$$\text{Total power} \quad . \quad . \quad = 845{\cdot}6$$

Out of this 845·6 lbs. of accumulated power, 288 lbs., or one-third of the whole, is due to the vacuum in the condenser, and 557·6, or two-thirds, to the steam.

It may be instructive to compare the power given out in a single cylinder of the same capacity, and using the same quantity of steam. Thus, Nap. log. of $4{\cdot}1 = 1{\cdot}411 \times 40 \times 6 \div 18{\cdot}6 = 17{\cdot}67$ lbs. as the mean pressure of expansion.

And as before—

$$\left.\begin{array}{lll} \text{Full pressure area} & = 6 \times 40 & = 240{\cdot}00 \\ \text{Expended press. area} & = 18{\cdot}6 \times 17{\cdot}67 & = 328{\cdot}66 \\ \text{Condenser vacuum} & = 24{\cdot}6 \times 12{\cdot}0 & = 295{\cdot}20 \end{array}\right\} \div 24 = 35{\cdot}99 \text{ lbs. mean pressure.}$$

$$\text{Total power} \quad . \quad . \quad . \quad = 863{\cdot}86$$

Now $863{\cdot}86 - 845{\cdot}6 = 18{\cdot}26$ lbs., or 2·16 per cent. in favour of the power given out on one cylinder; but with this greater power there is also much greater irregularity of motion. For various classes of machinery now driven by steam such irregular motion would be highly detrimental, whilst the more uniform motion produced by the double-cylinder engine enables the principle of expansion to be more extensively applied to general purposes than by the single-cylinder engine.

There are other modifications of the double or combined cylinder engine, where the cylinders are placed on the top of each other, and differently arranged to provide the utmost economy; but the diagram conveys the idea of their action more clearly than if mechanically correct in the arrangement of the steam passages or position of the cylinders. They are a valuable class of engines.

GENERAL REFERENCE TABLES.

Table, No. 57, contains the average properties of unexpanded steam of different temperatures and in various definitions.

Table, No. 57.

TEMPERATURE, PRESSURE, AND RELATIVE VOLUME OF STEAM FROM 212° TO 387·3° FAH. IN ENGLISH AND FRENCH MEASURES.

Pressure on a Square Inch, including the Pressure of the Atmosphere.		Elastic Force in		Temperature in Degrees of			Volume of Steam compared with the Volume of Water.	Power of 1 cub. ft. of water as steam in lbs. raised 1ft. high.
		Inches of Mercury.	Metres of Mercury.	Fahrenheit.	Reaum.	Cent.		
lbs.	kilog.	in.	metres.	deg.	deg.	deg.	lines.	lbs.
14·7	6·668	30·00	·762	212·0	80·0	100·0	1700	2083
15	6·80	30·60	·778	212·8	80·4	100·4	1669	2086
16	7·26	32·64	·829	216·3	81·9	102·4	1573	2097
17	7·71	34·68	·880	219·6	83·3	104·2	1488	2107
18	8·16	36·72	·932	222·7	84·7	105·9	1411	2117
19	8·62	38·76	·984	225·6	86·0	107·6	1343	2126
20	9·07	40·80	1·037	228·5	87·3	109·2	1281	2135
21	9·52	42·84	1·089	231·2	88·5	110·7	1225	2144
22	9·98	44·88	1·140	233·8	89·7	112·1	1174	2152
23	10·43	46·92	1·192	236·3	90·8	113·5	1127	2169
24	10·88	48·96	1·244	238·7	91·9	114·8	1084	2168
25	11·34	51·00	1·296	241·0	93·0	116·1	1044	2175
26	11·79	53·04	1·348	243·3	93·9	117·4	1007	2182
27	12·25	55·08	1·400	245·5	94·9	118·6	973	2189
28	12·70	57·12	1·452	247·6	95·8	119·8	941	2196
29	13·15	59·16	1·503	249·6	96·7	120·9	911	2202
30	13·61	61·21	1·555	251·6	97·6	122·0	883	2209
31	14·06	63·24	1·607	253·6	98·5	123·1	857	2215
32	14·51	65·28	1·659	255·5	99·3	124·2	833	2221
33	14·97	67·32	1·711	257·3	100·1	125·2	810	2226
34	15·42	69·36	1·763	259·1	100·9	126·2	788	2232
35	15·87	71·40	1·814	260·9	101·7	127·2	767	2238
36	16·33	73·44	1·866	262·6	102·5	128·1	748	2243
37	16·78	75·48	1·918	264·3	103·2	129·1	729	2248
38	17·23	77·52	1·970	265·9	104·0	129·9	712	2253
39	17·69	79·56	2·022	267·5	104·7	130·8	695	2259
40	18·14	81·60	2·074	269·1	105·4	131·7	679	2264
41	18·59	83·64	2·126	270·6	106·0	132·6	664	2268
42	19·05	85·68	2·178	272·1	106·7	133·4	649	2273
43	19·50	87·72	2·229	273·6	107·4	134·2	635	2278
44	19·96	89·76	2·281	275·0	108·0	135·0	622	2282
45	20·41	91·80	2·333	276·4	108·6	135·8	610	2287
46	20·86	93·84	2·385	277·8	109·2	136·6	598	2291
47	21·32	95·88	2·437	279·2	109·9	137·3	586	2296
48	21·77	97·92	2·489	280·5	110·4	138·1	575	2300
49	22·22	99·96	2·541	281·6	111·1	138·8	564	2304
50	22·68	102·00	2·592	283·2	111·6	139·6	554	2308
51	23·13	104·04	2·644	284·4	112·2	140·2	544	2312

Pressure on a Square Inch, including the Pressure of the Atmosphere.		Elastic Force in		Temperature in Degrees of			Volume of Steam compared with the Volume of Water,	Power of 1 cub. ft. of water as steam in lbs. raised 1 ft. high.
		Inches of Mercury.	Metres of Mercury.	Fahrenheit.	Reaum.	Cent.		
lbs.	kilog.	in.	metres.	deg.	deg.	deg.	lines.	lbs.
52	23·59	106·08	2·696	285·7	112·8	140·9	534	2316
53	24·04	108·12	2·748	286·9	113·3	141·6	525	2320
54	24·49	110·16	2·800	288·1	113·8	142·3	516	2324
55	24·95	112·20	2·852	289·3	114·4	142·9	508	2327
56	25·40	114·24	2·903	290·5	114·9	143·6	500	2331
57	25·85	116·28	2·955	291·7	115·4	144·3	492	2335
58	26·31	118·32	3·007	292·9	116·0	144·9	484	2339
59	26·76	120·36	3·059	294·2	116·5	145·7	477	2343
60	27·21	122·40	3·111	295·6	117·2	146·4	470	2347
61	27·67	124·44	3·163	296·9	117·7	147·2	463	2351
62	28·12	126·48	3·215	298·1	118·3	147·8	456	2355
63	28·57	128·52	3·266	299·2	118·8	148·4	449	2359
64	29·03	130·56	3·318	300·3	119·2	149·1	443	2362
65	29·48	132·60	3·370	301·3	119·7	149·6	437	2365
66	29·93	134·64	3·422	302·4	120·2	150·2	431	2369
67	30·39	136·68	3·474	303·4	120·6	150·8	425	2372
68	30·84	138·72	3·526	304·4	121·1	151·3	419	2375
69	31·29	140·76	3·577	305·4	121·5	151·9	414	2378
70	31·75	142·80	3·629	306·4	122·0	152·4	408	2382
71	32·20	144·84	3·681	307·4	122·4	153·0	403	2385
72	32·66	146·88	3·733	308·4	122·8	153·6	398	2388
73	33·11	148·92	3·785	309·3	123·2	154·1	393	2391
74	33·56	150·96	3·837	310·3	123·7	154·6	388	2394
75	34·02	153·02	3·889	311·2	124·1	155·1	383	2397
76	34·47	155·06	3·940	312·2	124·5	155·7	379	2400
77	34·93	157·10	3·992	313·1	124·9	156·2	374	2403
78	35·38	159·14	4·044	314·0	125·3	156·7	370	2405
79	35·83	161·18	4·096	314·9	125·7	157·2	366	2408
80	36.29	163·22	4·148	315·8	126·1	157·7	362	2411
81	36·74	165·26	4·199	316·7	126·5	158·2	358	2414
82	37·19	167·30	4·252	317·6	126·9	158·7	354	2417
83	37·65	169·34	4·303	318·4	127·3	159·1	350	2419
84	38·10	171·38	4·355	319·3	127·7	159·6	346	2422
85	38·55	173·42	4·407	320·1	128·0	160·1	342	2425
86	39.01	175·46	4·459	321·0	128·4	160·6	339	2427
87	39·46	177·50	4·511	321·8	128·8	161·0	335	2430
88	39 91	179·54	4·563	322·6	129·2	161·4	332	2432
89	40.37	181·58	4·615	323·5	129·6	161·9	328	2435
90	40·82	183·62	4·666	324·3	129·9	162·4	325	2438
91	41·27	185·66	4·718	325·1	130·3	162·8	322	2440
92	41·73	187·70	4·770	325·9	130·6	163·3	319	2443
93	42·18	189·74	4·822	326·7	131·0	163·7	316	2405
94	42·64	191·78	4·874	327·5	131·3	164·2	313	2448
95	43·09	193·82	4·926	328·2	131·6	164·8	310	2450

Pressure on a Square Inch, including the Pressure of the Atmosphere.		Elastic Force in		Temperature in Degrees of			Volume of Steam compared with the Volume of Water.	Power of 1 cub. ft. of water as steam in lbs. raised 1 ft. high.
		Inches of Mercury.	Metres of Mercury.	Fahrenheit.	Reaum.	Cent.		
lbs.	kilog.	in.	metres.	deg.	deg.	deg.	lines.	lbs.
96	43·54	195·86	4·977	329·0	132·0	165·0	307	2453
97	44.00	197·90	5·029	329·8	132·4	165·4	304	2455
98	44·45	199·92	5·081	330·5	132·7	165·8	301	2457
99	44·90	201·96	5·133	331·3	133·0	166·3	298	2460
100	45·36	204·01	5·185	332·0	133·3	166·7	295	2462
110	49·89	224·40	5·703	339·2	136·5	170·7	271	2486
120	54·43	244·82	6·222	345·8	139·5	174·3	251	2507
130	58·97	265·23	6·740	352·1	142·3	177·8	233	2527
140	63·50	285·61	7·259	357·9	144·8	181·1	218	2545
150	68·04	306·03	7·778	363·4	147.3	184·1	205	2561
160	72·57	326·42	8·296	368·7	149·6	187·1	193	2577
170	77·11	346·80	8·814	373·6	151·8	189·8	183	2593
180	81·65	367·25	9·333	378·4	153·9	192·4	174	2608
190	86·18	387·61	9·851	382·9	156·0	194·9	166	2622
200	90·72	408·04	10·370	387·3	157·9	197·4	158	2636
210	95·23	428·42	10·88	391·3	159·7	199·6	151	2650
220	99·77	448·82	11·39	395·5	161·2	201·9	145	2663
230	104·3	469·22	11·91	399·4	163·3	206·9	140	2675
240	108·8	489·62	12·43	403·1	164·9	206·1	134	2689

Table, No. 58, contains the specific quantity and power of a cubic foot of water evaporated per hour under various pressures.

The relative weight of steam to water is nearly as their relative volumes. Thus, in Table No. 57, the relative volume of steam of atmospheric pressure is given as 1700, therefore the weight of a cubic foot of steam is $\frac{1}{1700}$th part of a cubic foot of water, or 256·7 grains, as given in Table No. 58. For a cubic foot of water = 62·32 lbs. × 7000 grains troy each lb., so that 436,240 grains ÷ by 1700 = 256·7 grains; and for other pressures use the ratio of the volume for a divisor.

Inches of mercury × ·4919 = lb. avoirdupois, and lb. av. × 2·03294 = inches of mercury.

Table, No. 60, contains the Arithmetical Pressures, Means and Ratios of a Power of 1, expanded 24 times and at 24 different ordinates of any stroke, illustrated by Diagram, No. 50, and page 206.

Table, No. 58.

POWER OF STEAM FROM ONE CUBIC FOOT OF WATER GENERATED UNDER VARIOUS PRESSURES.

DESCRIPTION OF STEAM.					ITS MECHANICAL FORCE OR POWER.				IN A HIGH PRESSURE ENGINE.			
		Specific Gravity.			Power = to a				Taking the Horse Power as 30,000 lbs.			
			Weight of a Cubic Foot.									
Temp.	Pressure in	Spec. Grav. to Air = 1.	in	in	Weight of	Raised to a Height of	Or a Weight raised 1 Foot of	Or, in Horse Power of 33,000 lbs.	Tot al Po wer.	Atmospheric Resistance in		Available Power.
Fah.	lbs.	Ratio.	grs. troy	lbs. av.	lbs.	ft.	lbs.	H. P.	H. P.	lbs.	H. P.	H. P.
212	14·706	·477	256·7	·0366	2117·6	1700	60,000	1·818	2·000	60,000	2·000	—
212·8	15	·488	261·4	·0373	2160	1669	60,084	1·821	2·0028	58,904	1·963	·0384
220	17·5	·560	300·8	·0429	2520	1450	60,900	1·845	2·0300	51,175	1·706	·324
228·5	20	·635	340·5	·0486	2880	1281	61,488	1·863	2·0496	45,210	1·507	·542
234·2	22·5	·708	379·3	·0542	3240	1150	62,100	1·882	2·0700	40,587	1·353	·617
244·5	26·25	·814	436·2	·0627	3780	1000	63,000	1·909	2·100	35,293	1·176	·924
251·6	30	·922	494	·0757	4320	883	63,576	1·926	2·1192	31,164	1·039	1·080
264·9	37	1·131	605·9	·0865	5400	720	64,800	1·963	2·160	25,411	·847	1·313
269·1	40	1·199	642·5	·0918	5760	679	65,184	1·975	2·1728	23,964	·799	1·373
276·4	45	1·334	715·1	·1021	6480	610	65,880	1·996	2·1960	21,529	·717	1·479
283·2	50	1·469	787·4	·1125	7200	554	66,480	2·013	2·2160	19,552	·652	1·564
286·3	52·5	1·536	823·1	·1176	7560	530	66,766	2·034	2·2383	18,705	·623	1·613
295·6	60	1·736	930	·1328	8640	470	67,680	2·051	2·2560	17,254	·575	1·671
306·4	70	1·996	1069·2	·1527	10080	408	68,544	2·077	2·2848	14,400	·480	1·804
311·3	75	2·126	1139	·1627	10800	383	68,960	2·089	2·2986	13,517	·450	1·848
315·8	80	2·249	1205·1	·1721	11520	362	69,504	2·106	2·3168	12,776	·426	1·89
324·3	90	2·505	1342·3	·1917	12960	325	70,200	2·117	2·3400	11,470	·382	1·958
328·2	95	2·627	1407·2	·2010	13680	310	70,680	2·141	2·356	10,941	·364	1·992
332	100	2·760	1478·8	·2112	14400	295	70,800	2·145	2·3600	10,411	·347	2·013
333·2	105	2·877	1541·4	·2202	15120	283	71,316	2·161	2·3772	9,986	·333	2·044
339·2	110	3·005	1610·1	·2300	15840	271	71,544	2·168	2·3848	9,565	·318	2·066
342·5	114·7	3·120	1671·4	·2387	16517·6	261	71,851	2·177	2·3950	9,212	·307	2·088
345·8	120	3·257	1744·9	·2492	17280	250	72,000	2·182	2·4000	8,823	·294	2·106
352·1	130	3·494	1872·2	·2674	18720	233	72,696	2·203	2·4232	8,223	·274	2·149
352·4	135	3·619	1938·8	·2765	19440	225	73,224	2·219	2·4408	7,941	·264	2·176
357·9	140	3·733	2000·1	·2857	20160	218	73,250	2·220	2·4416	7,694	·256	2·185
263·4	150	3·969	2128	·3040	21600	205	73,600	2·230	2·4533	7,235	·241	2·212
368·7	160	4·241	2272·1	·3245	23040	192	73,728	2·234	2·4576	6,776	·226	2·231
371·1	165	4·354	2332·8	·3332	23760	187	74,052	2·244	2·4684	6,570	·219	2·249
373·6	170	4·474	2396·9	·3989	24480	182	74,256	2·250	2·4752	6,423	·214	2·261
378·4	180	4·771	2521·6	·3602	25920	173	74,736	2·264	2·4912	6,105	·203	2·288
382·9	190	4·935	2643·9	·3777	27360	165	75,240	2·280	2·5080	5,823	·194	2·314
385·1	195	5·058	2709·6	·3870	28080	161	75,348	2·283	2·5116	5,682	·189	2·322
387·3	200	5·186	2778·6	·3968	28800	157	75,569	2·290	2·5189	5,541	·184	2·334
389·6	210	5·537	2906·6	·4152	30240	150	75,600	2·291	2·5200	5,294	·176	2·344
393	220	5·655	3029·5	·4328	31680	144	76,032	2·304	2·5344	5,082	·169	2·365
395	225	5·776	3093·9	·4420	32400	141	76,140	2·307	2·5380	4,960	·165	2·373
402	240	6·126	3280	·4685	34560	133	76,608	2·321	2·5536	4,694	·156	2·397
414	300	7·366	3930·1	·5614	43200	111	79,920	2·421	2·664	3,751	·128	2·539
456	450	10·179	5453	·779	62800	80	83,733	2·537	2·7911	2,823	·094	2·697
478	600	13·574	7270·8	1·0387	86400	60	86,400	2·617	2·8800	2,117	·070	2·810

Table, No. 59.

NAPIERIAN OR HYPERBOLIC LOGARITHMS.—Page 205.

Num.	Nap. Log.	Num.	Nap. Log.	Num.	Nap. Log.	Num.	Nap. Log.	Num.	Nap. Log.
1·05	·049	3·05	1·115	5·05	1·619	7·05	1·953	9·05	2·203
1·1	·095	3·1	1·131	5·1	1·629	7·1	1·960	9·1	2·208
1·15	·140	3·15	1·147	5·15	1·639	7·15	1·967	9·15	2·214
1·2	182	3·2	1·163	5·2	1·649	7·2	1·974	9·2	2·219
1·25	223	3·25	1·179	5·25	1·658	7·25	1·981	9·25	2·225
1·3	262	3·3	1·194	5·3	1·668	7·3	1·988	9·3	2·230
1·35	300	3·35	1·209	5·35	1·677	7·35	1·995	9·35	2·235
1·4	336	3·4	1·224	5·4	1·686	7·4	2·001	9·4	2·241
1·45	372	3·45	1·238	5·45	1·696	7·45	2·008	9·45	2·246
1·5	405	3·5	1·253	6·5	1·705	7·5	2·015	9·5	2·251
1·55	438	3·55	1·267	5·55	1·714	7·55	2·022	9·55	2·257
1·6	470	3·6	1·281	5·6	1·723	7·6	2·028	9·6	2·262
1·65	500	3·65	1·295	5·65	1·732	7·65	2·035	9·65	2·267
1·7	531	3·7	1·308	5·7	1·740	7·7	2·041	9·7	2·272
1·75	560	3·75	1·322	5·75	1·749	7·75	2·048	9·75	2·277
1·8	588	3·8	1·335	5·8	1·758	7·8	2·054	9·8	2·282
1·85	615	3·85	1·348	5·85	1·766	7·85	2·061	9·85	2·287
1·9	642	3·9	1·361	5·9	1·775	7·9	2·067	9·9	2·293
1·95	668	3·95	1·374	5·95	1·783	7·95	2·073	9·95	2·298
2·0	693	4·0	1·386	6·0	1·792	8·0	2·079	10·	2·303
2·05	718	4·05	1·399	6·05	1·800	8·05	2·086	15·	2·708
2·1	742	4·1	1·411	6·1	1·808	8·1	2·092	20·	2·996
2·15	765	4·15	1·423	6·15	1·816	8·15	2·098	25·	3·219
2·2	788	4·2	1·435	6·2	1·824	8·2	2·104	30·	3·401
2·25	811	4·25	1·447	6·25	1·833	8·25	2·110	35·	3·555
2·3	833	4·3	1·459	6·3	1·841	8·3	2·116	40·	3·689
2·35	854	4·35	1·470	6·35	1·848	8·35	2·122	45·	3·807
2·4	875	4·4	1·482	6·4	1·856	8·4	2·128	50·	3·912
2·45	896	4·45	1·493	6·45	1·864	8·45	2·134	55·	4·007
2·5	916	4·5	1·504	6·5	1·872	8·5	2·140	60·	4·094
2·55	936	4·55	1·515	6·55	1·879	8·55	2·146	65·	4·174
2·6	956	4·6	1·526	6·6	1·887	8·6	2·152	70·	4·248
2·65	975	4·65	1·537	6·65	1·895	8·65	2·158	75·	4·317
2·7	993	4·7	1·548	6 7	1·902	8·7	2·163	80·	4·382
2·75	1·012	4·75	1·558	6·75	1·910	8·75	2·169	85·	4·443
2·8	1·030	4·8	1·569	6·8	1·917	8·8	2·175	90·	4·500
2·85	1·047	4·85	1·579	6·85	1·924	8·85	2·180	99·	4·554
2·9	1·065	4·9	1·589	6·9	1·931	8·9	2·186	100·	4·605
2·95	1·082	4·95	1·599	6·95	1·939	8·95	2·192	1000·	6·908
3.0	1·099	5·0	1·609	7·0	1.946	9·0	2·197	10,000·	9·210

Note.—Hyperbolic logarithms express the areas of the irregular spaces or divisions of the rectangular hyperbola whose congregate and transverse axes are equal, and whose ordinates decrease in geometrical progression. Common logarithms multiplied by 2·30258 give hyperbolic or Napierian logarithms.

TABLE, No. 60.—RELATIVE PRESSURES OF STEAM EXPANDED TO TWENTY-FOUR TIMES.—Page 206.

	RELATIVE LENGTHS OF ORDINATES WHEN STEAM IS CUT OFF AS FIG. No. 50.																							
Full pressure =	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Full to expan. =	$\frac{1}{24}$	$\frac{1}{12}$	$\frac{1}{8}$	$\frac{1}{6}$	$\frac{5}{24}$	$\frac{1}{4}$	$\frac{7}{24}$	$\frac{1}{3}$	$\frac{3}{8}$	$\frac{5}{12}$	$\frac{13}{24}$	$\frac{1}{2}$	$\frac{13}{24}$	$\frac{7}{12}$	$\frac{5}{8}$	$\frac{2}{3}$	$\frac{17}{24}$	$\frac{9}{12}$	$\frac{19}{24}$	$\frac{5}{6}$	$\frac{5}{8}$	$\frac{11}{12}$	$\frac{23}{24}$	24
Expand· to full=	$\frac{23}{24}$	$\frac{11}{12}$	$\frac{7}{8}$	$\frac{5}{6}$	$\frac{19}{24}$	$\frac{3}{4}$	$\frac{17}{24}$	$\frac{2}{3}$	$\frac{5}{8}$	$\frac{7}{12}$	$\frac{11}{24}$	$\frac{1}{2}$	$\frac{11}{24}$	$\frac{5}{12}$	$\frac{3}{8}$	$\frac{1}{3}$	$\frac{7}{24}$	$\frac{3}{12}$	$\frac{5}{24}$	$\frac{1}{6}$	$\frac{3}{8}$	$\frac{1}{12}$	$\frac{1}{24}$	0
1	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
2	·5	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
3	·333	·666	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
4	·25	·5	·75	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
5	·2	·4	·6	·8	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
6	·166	·333	·5	·666	·833	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
7	·143	·285	·428	·571	·714	·857	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
8	·125	·25	·375	·5	·625	·75	·875	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
9	·111	·222	·333	·444	·555	·666	·777	·888	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
10	·10	·2	·3	·4	·5	·6	·700	·800	·900	1·	1·	1.	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
11	·0909	·1818	·2727	·363	·454	·545	·636	·727	·818	·909	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
12	·0833	·166	·25	·333	·416	·5	·583	·666	·750	·833	·916	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
13	·0769	·154	·23	·307	·385	·461	·538	·615	·692	·769	·846	·923	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
14	·0714	·143	·214	·285	·357	·428	·500	·571	·642	·714	·785	·857	·928	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
15	·0666	·133	·2	·266	·333	·40	·4666	·533	·600	·666	·738	·800	·866	·933	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
16	·0625	·125	·187	·25	·312	·375	·437	·500	·5625	·625	·687	·750	·812	·875	·937	1·	1·	1·	1·	1·	1·	1·	1·	1·
17	·0588	·117	·176	·235	·294	·353	·4116	·472	·5294	·588	·647	·706	·764	·823	·882	·941	1·	1·	1·	1·	1·	1·	1·	1·
18	·0555	·111	·166	·222	·277	·333	·3882	·444	·500	·555	·611	·666	·722	·777	·838	·888	·944	1·	1·	1·	1·	1·	1·	1·
19	·0526	·105	·157	·21	·263	·315	·3682	·421	·473	·526	·578	·630	·684	·736	·790	·842	·894	·947	1·	1·	1·	1·	1·	1·
20	·050	·1	·150	·20	·25	·3	·350	·400	·450	·500	·550	·600	·650	·700	·750	·800	·850	·900	·95	1·	1·	1·	1·	1·
21	·0476	·095	·142	·19	·238	·285	·3333	·380	·4285	·476	·523	·571	·619	·666	·714	·761	·809	·857	·904	·952	1·	1·	1·	1·
22	·0454	·0909	·136	·181	·227	·272	·3178	·363	·4090	·454	·500	·545	·590	·635	·681	·727	·772	·818	·863	·909	·954	1·	1·	1·
23	·0434	·087	·13	·173	·217	·26	·3038	·347	·3913	·436	·477	·520	·565	·607	·652	·695	·739	·782	·826	·869	·913	·956	1·	1·
24	·0416	·0833	·125	·166	·208	·25	·2916	·333	·3750	·416	·458	·500	·541	·583	·625	·666	·708	.750	·791	·833	·875	·916	·958	1·0
Expan. power =	2·774	4·547	5·821	6.762	7.458	7·950	8·277	8·460	8·520	8·467	8·316	8·068	7·741	7·335	6·870	6·320	5·716	5·054	4·334	3·563	2·742	1·872	·958	·00
Total power - =	3·774	6·547	8·821	10·762	12·458	13·950	15·277	16·460	17·520	18·467	19·316	20·068	20·741	21·335	21·870	22·320	22·716	23·054	23·334	23·563	23·742	23·872	23·958	24·
Ex. to full as 1· =	2·774	2·273	1·974	1·69	1·491	1·325	1·182	1·057	·946	·851	·756	·672	·595	·524	·458	·395	·336	·281	·228	·178	·130	·085	·041	·00
Means of exp. pr.=	·1206	·2067	·277	·333	·392	·441	·486	·528	·568	·608	·639	·672	·704	·733	·763	·790	·816	·842	·866	·895	·914	·936	·958	·00
Mns. of total pr.=	·157	·272	·367	·448	·518	·581	·636	·685	·730	·771	·804	·836	·864	·889	·911	·930	·946	·960	·972	·981	·989	·994	·998	1·0

⁎ The Means of full pressure are each taken as a power = 1; and the Exp. and total Means are each their relative proportion to the initial pressure as = 1.

Application of Steam Tables.

To find the power of water as steam (Tables 57, 58).

1st. Multiply the pressure in lbs. per square inch by the relative volume of steam to water, and divide by twelve for the lbs. raised one foot by one cubic inch of water as steam.

2nd. Multiply the pressure in lbs. per square foot by the relative volume of steam to water for the lbs. raised one foot by one cubic foot of water as steam.

Ex.—Required the power of water as steam of atmospheric pressure, or 14·706 lbs. per square inch, and its relative volume $= 1700$?

1st. $14{\cdot}706 \times 1700 \div 12 = 2083$ lbs. raised 1 foot by 1 cubic inch of water.

2nd. $14{\cdot}706 \times 144$ sq. in. $\times 1700 = 3{,}600{,}028$ lbs. raised 1 foot by 1 cubic foot of water.

The horse-power dynam. is variously estimated from 22,000 to 44,000 lbs. raised one foot, and Watt adopted 33,000 lbs.; but the advantage of a more simple unit has many advocates. Taking the power of a cubic foot of water as steam of atmospheric pressure, as 3,600,028 lbs. per hour, it gives 60,000 lbs. per minute, or say two horse-power of 30,000 lbs. This convenient multiple of three, founded on the natural law of atmospheric pressure, is adopted in Table 58, to promote the desired simplicity.

The usual 33,000 lb. dynam. is also a multiple of three; hence one-tenth the number of these dynams. *added to them* gives the number of 30,000 lb. dynams., and one-eleventh of the 30,000 lb. dynams. *deducted* from themselves leaves the number of 33,000 lb. values from the same amount of power in lbs. raised one foot.

Ex.—If steam of 45 lbs. pressure from 1 cubic foot of water raises 65,880 lbs. 1 foot high per minute (Table 59), required the horse power thereof?

1st. $65880 \div 30000 = 2{\cdot}196$ h. p.—$\frac{1}{11}$th $= 1{\cdot}996$ h.p. of 33,000 lbs. value.
2nd. $65880 \div 33000 = 1{\cdot}996$ h. p. $\div \frac{1}{10}$th $= 2{\cdot}196$ h. p. of 30,000 lbs. value.

Power of Expanded Steam, Tables 58, 59.

To find the power of any ordinate, or mean expansion, or mean total power, multiply the respective tabular number by the initial pressure in pounds per square inch.

For the total power of a boiler, multiply the given evaporation in cubic feet per hour by the power in lbs., or in horse-power due to the given temperature or pressure in Table 59; and for the gain by expansion add the product of this power multiplied by the *Ratio* of the given expansion in Table 58.

For the available power of a high-pressure boiler or engine, from the total gross power as last found, deduct the atmospheric resistance in Table 59, multiplied by the evaporation per cubic foot per hour, and this product also multiplied by the *relative time* of expansive to full pressure action.

Ex.—Required the length of the 20th ordinate of expansion when the steam of 100 lbs. pressure is cut off at a quarter of its stroke?

Opposite the 20th ordinate in the Table, and under 4, the ratio of e-d pansion, is ·30, which being multiplied by the pressure 100 = 30 lbs. the pressure required.

Ex.—Required the total and available horse-power of a high-pressure boiler evaporating 100 cubic feet of water per hour, under a pressure of 100 lbs. per square inch? Also, when working an engine three-fourths expansively?

1st.—Total Power.

100 lbs. pres. Table 59 = 2·36 h. p. × 100 c. f. evap. = 236·00 h. p.
$\frac{1}{4}$ full pres. Table 58 = 1·32 ratio × 236·00 = 311·52 h. p.

Total power = 547·52 h. p.

2nd.—Atmospheric Resistance.

At. res. of 100 lbs. pres. = ·347 h. p. × 100 evap. = 34·7 h. p. to full pressure, and 34·7 h. p. × 4 ratio of exp. = 138·8 h. p. of atm. res. to overcome, when the steam is expanded 4 times.

3rd.—Available Power.

Full press. = 236·00 h. p.—atm. res. of 34·7 h. p. = 191·30 h. p., and exp. 4 times = 547·52 h. p.—atm. res. of 138·8 h. p. = 408·72 h. p.

available power in a cylinder, where no loss arises in transmitting it there from the boiler.

SECTION III.

OUTLINE OF STEAM HISTORY.

CHAPTER I.

ANCIENT STEAM AND HOT AIR ENGINES.

THE genealogy of steam, or hot air power, like that of heraldry, or science, or mechanics, or manufactures, passes into the romance of antiquity, and is besides involved in the secrecy of idolatrous worship, which has left only scanty means to trace it.

These means are historical allusions, but chiefly a philosophical treatise on the "Inventions of the Ancients," by Hero, of Alexandria, a pupil of Ctesibus, whose time is variously estimated as from 225 to 150 B. C.

Historically, however, since Hero recorded the existence of the steam-engine in an existing language, no retrogression marks its onward progress. An outline, therefore, of its history will more pleasingly convey rudimentary instruction on the application of steam power, than could be done by abstract reasoning. By this plan there is also the advantage of bringing into converse, as it were, the inventive ideas of past and present steam-engine improvers; for Boyle well remarked, that failures are as instructive as successes. The practice of seeking to enhance modern science by disparaging that of past ages is too often done, and we regret to find one so eminent as Dr. Lardner attempting to show that the ancients were ignorant of steam, because they described it as "air produced by heat from water."

As we have shown, steam is still treated as air in its elastic properties; and if these properties are described and acted

upon, it is evidence of knowledge; for the description of any new discovery is necessarily comparative until a name is adopted.

Following the course usually adopted in giving practical forms to the descriptions of inventors, such as those of the Marquis of Worcester and others, two of Hero's altar engines will be shown as cranes, with a view of usefully illustrating the romance of steam and hot air engines.

To make these more clear, Homer's ships, which "plow with reason up the deeps," and Plato's reference to steam, will be first noticed.

Homer, 927 B. C.—It is uncertain how long steam power may have been employed; but in cooking it would early display its force, and lead ingenious minds to apply it otherwise. When the word "steam" was generally used for the vapour of water is not known; but Homer speaks of "steam" from roasting meat, as it is yet spoken of; and his description of the Phæacian ships is an instance of great power being poetically, if not really, existent.

In Ogilby's edition of his Odyssey, dated 1699, Homer makes the Phæacian Prince thus address Ulysses the Greek:—

"Now, Sir, be pleased you would yourself declare,
Where you were born and what your Parents are,
And your Aboads: that so we may instruct
Our Ship, you to your Country to conduct;
We use nor Helm nor Helms-man. Our tall ships
Have Souls, and plow with Reason up the deeps.
All Cities, Countries know, and where they list,
Through Billows glide veiled in obscuring Mist;
Nor fear they Rocks, nor Dangers on the way,
But once I heard my sire, Nausithous, say,
Neptune enraged, because we do transport
So many people safe from Port to Port,
Returning will our vessel sink." * * *

This is a glowing description of navigation, conceived and described about 2800 years ago, if not partly realized by

some potent agent whose powers seemed illimitable to Homer. In various other passages, when describing Grecian ships, oars only are referred to, as in Ulysses' command to avoid a rock :—

> " Sit on your Banks with pliant Oars to sweep,
> All as one man, the surface of the deep ;
> But Helmsman thy care the vessel must protect."

Paddle-wheel boats moved by manual, or horse, or other power, and oars, are the only ancient propellers now known besides sails.

If, then, those " renowned Phæacians," or ancient Egyptians, employed neither horse, nor steam, nor other potent motive agent to propel their ships, then Homer conceived and clothed with brilliant language a Great Idea, all but literally translated by recent Navigation.

From the well-known science of the Egyptians; from Homer's frequent reference to "Hecatombs of Cattell," sacrificed to propitiate the gods, accompanied by wood, fire, and water to the altar, and completed by LIBATIONS of wine poured on the sacrifice, as

> " On burning Altars a Libation due,"

we can scarcely doubt but that they were well acquainted with steam power as used in religious services ; and as Homer's assertion to Ulysses,

> " Since at Contrivements we are Skilful both
> For dex'trous Sleights, 'mongst Mortals thine's the prize,"

is attested by their existing monuments, it would be easy for such "skilful contrivers" to convert a "wine or water-raising engine" into a stone-raising one useful in the arts.

Plato, 390 B. C.—The prevailing darkness regarding the scientific and practical knowledge of the ancients is in a great

measure due to the philosophers of those days, such as Plato, considering it derogatory to explain science to the uninitiated, or record the inventions of the "vulgar," however meritorious, beyond a passing allusion to them in other subjects.

Plato describes steam as water melted into air by heat, which could be compressed into water again—a very correct description of the generation and condensation of steam, although that word is not used.

He also makes Timæus speak of ingenious inventions in the mechanical arts ; and from Plato's particular notice of steam power, it is evident that it was then a familiar object to learned and ingenious men, and may have been equally so in Homer's time. Neither can it be doubted that Aristotle, one of Plato's disciples, who died 322 B. C., Euclid, the mathematician, who flourished 300 B. C., Archimedes, the great geometrician and mechanician, who was basely slain 212 B.C., would be all conversant with steam and the steam mechanism of their days.

More particularly in the noble defence of Syracuse against the Romans is Archimedes believed to have employed steam in some of his defensive engines, whilst with his burning-lenses he attacked the invaders, and drew the attention of the world to the resources of mechanical science.

Hero, 150 B. C.—About this time, if not before, Hero of Alexandria wrote his able treatise on the "Inventions of the Ancients" of his day, which has associated his name with the invention of the steam-engine, although it appears to have been known some thousand years before his time. Hero states that some of the seventy-eight inventions he describes were his own, but does not specify which they are.

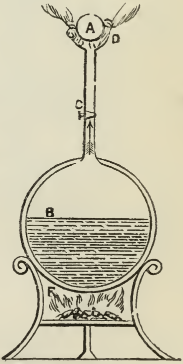
Like other sources of information, extending beyond the burning of the Alexandrian Library of 400,000 volumes by the Saracens under Omar, 640, A.D., steam, in all probability, also lost its records. Hero's treatise was written before this

dire event, but policy would guide his selections from the records of former inventors, which he professedly gives.

In a commendable spirit of justice, Professor Woodcroft, of University College, London, and Professor Greenwood, of Owen College, Manchester, have jointly published a carefully revised edition of Hero's treatise on Pneumatics, which describes and illustrates seventy-eight "Ancient Inventions."*

Many of them are very ingenious, and display a knowledge of the properties of steam, air, and water. Amongst the number are a syphon, a fire-engine pump, a water-clock, steam-engines, altar-libation engines, singing-birds, and other devices, ending in an automaton drinking water after a knife had passed through its neck. They would well repay a careful examination†.

Fig. No. 52.



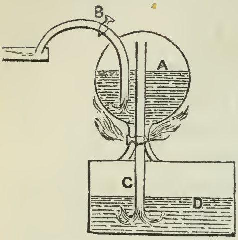
Ancient Steam-Engine.

Hero's 45th invention, Fig. No. 52, illustrates the force of steam in raising a weight A out of its seat in D, as it passes up the pipe C from the boiler B, in which it is generated by the fire F, which would also equally move a piston in a cylinder. This is still occasionally a lecture experiment; and the locomotive ball-valve is similar in its construction and action, by being raised from its seat by the water pumped into the boiler.

* Taylor and Walton, London.

† Hero also wrote four other treatises still extant, on "Missiles," on "Automata," on the "Dioptra" or spying tube, and on "Lifting heavy Bodies." A translation of the last would be a useful addition to Woodcroft's translation of the "Pneumatical Treatise," since there is no work existing on the every-day mechanism of the Antediluvians, or of the immediate descendants of Noah, acquainted with mechanism in use both before and after the flood.

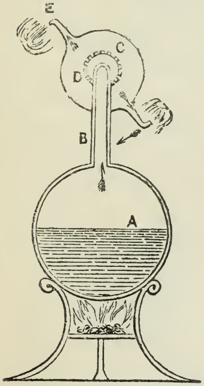
FIG. No. 53.



Ancient Hot Air Engine.

Hero's 47th invention, Fig. No. 53, is designed for the heat of the sun to expand the water in A, and by compressing the air on its surface jointly with the vapour formed, to force the contents in A up the pipe B. When A is cooled, the water in D would rise to fill the partial vacuum in A, and be emptied as before. By substituting a fire below A instead of the sun above it, we have a simple water-raising engine on De Caus's plan, but wanting the separate cylinders to make it either as complete or economical as the idolatrous engine, Fig. 55.

FIG. No. 54.



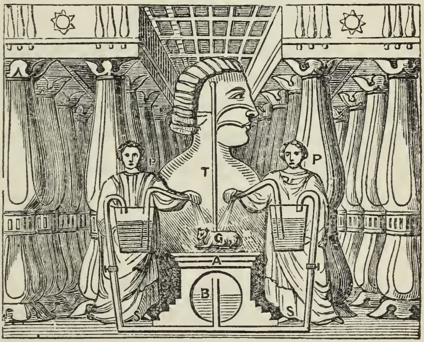
Ancient Rotatory Engine.

Hero's 50th invention, Fig. No. 54, is a simple yet complete rotatory steam-engine, capable of giving motion to machinery. The steam generated in A passes up the hollow frame B into the globe C, freely suspended on the point of B and on an opposite centre. The steam then issues at an orifice on one side only of each arm E F, against the air, whose resistance causes these arms to recede in an opposite direction and produce rotation of the globe C. If the steam had issued at both sides of the arms the resistances would have balanced each other without obtaining rotation, similarly to two persons of equal power opposing each other in opening a gate. By a pinion D, or pulley on the solid centre of the globe, motion could be communicated to machinery; and a modified engine of this class was recently employed in the printing establishment of the Messrs. Chambers of Edinburgh.*

* Before noticing the altar-engines, it may be interesting to state, that the properties of the atmosphere and a vacuum are discussed by Hero as

Altar-Engines.—Hero's description of these engines shows a clear knowledge how to apply the powers of steam or hot air to raise fluids. His 11th and 60th inventions, entitled "Libations at an Altar by Fire," and "Libations poured on an Altar, and a Serpent made to hiss, by Fire," display both scientific and practical skill. For on a large scale both libation-engines would be quite capable of exerting immense lifting power. One example will therefore be given as both morally and practically instructive on this point.

FIG. No. 55.



Double-acting Idolatrous Engine.

"I am all that has been, is, or will be; and no mortal has ever lifted my veil."—Isus.

Let Fig. No. 55 represent Isus in his splendid temple with

they still are; that various figures illustrate the motive power between water and air-pressure; that Figs. 9, 49, and 54 show the power of compressed air; Fig. 27 an effective fire-extinguishing engine with two bronze cylinders, "bored in a lathe to fit pistons," and each piston connected to one end of a beam vibrating on its centre, as in modern engines; Figs. 11, 37, 38, 60, and 70, the power of hot air, or hot air with steam; Fig. 57, a syringe; Figs. 4, 33, 68, and 78 the screw-press, rack and pinion, bevel-gear, pulleys, and counter-weights; Figs. 74 and 75, cylindrical boilers with inner concentric hot air chambers or fire-

the altar A*, sacrifice C, and the attendant altar guardians. Part of it is sectional, to show the secret engine clearly. B, the boiler from which the steam passes by the pipes S S into the wine cylinders to force their contents out by the pipes along the priest's arms, similar to Porta's, Worcester's, Morland's, Papin's, and Savary's and other similar water-raising engines. The wine pipes terminate in cups held by the priests, and a third steam-pipe, T, passes from the boiler to the idol's head, with branches to the mouth, or nose, or both. With convenient stop-cocks, and all concealed from view, this mechanism gave great power of deception.

Suppose, for instance, that the priestly exhortations were ended, and the worshippers expected the public sanction of the idol, hot air or steam admitted to the head would give the oracular response on any concealed musical or other mechanism there, whilst the steam would escape like breathing. In like manner with the sacrifice, steam or hot air admitted to the wine cylinders would cause it to flow out into the cups as if miraculously obtained. Since it better accounts for

places, (in which a fire-pan and grate could be let down, as in Moses' altar of burnt offerings,) and tubes for admitting air, for blowing the fire by hot air, for blowing a trumpet, and for whistling like a blackbird ; Fig. 76, an organ-blowing cylinder, with slide valves to each pipe, worked by a bell crank motion similar to the rocking shaft valve motion of locomotives, or Ericcson's caloric engine ; and Fig. 77, a wind-mill working an organ-blowing cylinder. In the most elaborate of these designs, hot-air power is a leading feature, aided by steam to increase its effect.

* In the British Museum, Egyp. Gal., No. 135, is a small altar of libations, with a central tank (or boiler like Brindley's stone ones), and in the bottom are three holes, as if for pipes, arranged after Hero's design. In the Egypt Room, cases 24-5, is a libation vase with a large strap-like oval hole through it, and which divides it at that part into two separate vessels, but forming one vessel only at the top and bottom. This vase could be easily bound to any person or object, and its tubular orifice convey hot air or steam into it, whilst another similar tube might lead from its top—now broken off—to a cup in the priest's hand.

various historic records of scenes at idolatrous worship unaccountable to the witnesses, we have merely altered Hero's original "serpent's head hissing" for a man's head, as a statue, on which the heat of an eastern sun would generate steam of available force from any water concealed in it.*

Air would also produce similar effects when heated. By admitting it at one opening, and its expansion by heat shutting that entrance and opening another for escape, the heat of the sun would give sufficient power to emit sounds.

Philostratus states that sounds proceeded from Memnon like a stringed instrument, when the sun shone. Pausanius compares them to snapping the strings of a harp, and Strabo mentions his having heard similar sounds. Thus:

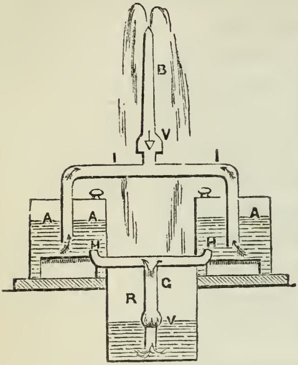
> " Memnon's broken image sounding,
> Tuneful 'midst desolation still."

Closed from the air, a little water confined in any exposed part of this celebrated idol would produce these sounds again and again, "when the sun shone." As such water would be literally in the position sought by some modern steam engineers, viz., to use the same water over and over again without loss, it would be a question of time how long water entirely excluded from the air would retain its usual properties of generating steam to produce these sounds, and at what temperature it would be produced.

De Caus's Sun Fountains, 1612.—The recorded movements of idols when the sun rose, and of the sounds proceeding from them, led the mechanics of the 17th century to imitate them by various ingenious arrangements of mechanical music. Amongst these was De Caus; and as showing the power of the sun on confined water, we give in this place two of his illustrations of ancient sun fountains, which may be otherwise interesting in these days of Crystal Palace fountains.

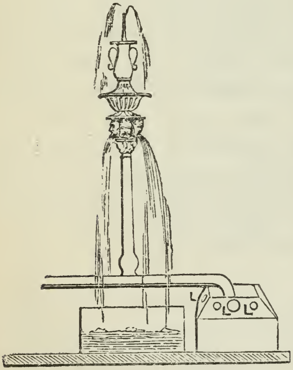
* Serpents were formerly venerated as idols.

Fig. No. 56.



Sun Fountain.

Fig. No. 57.



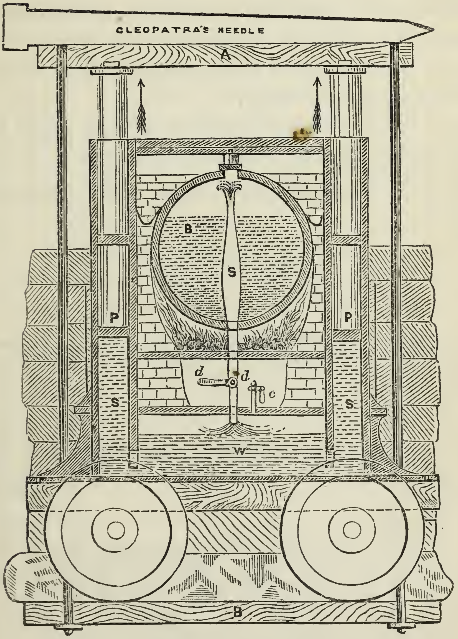
Lensed Sun Fountain.

Fig. No. 56 is a sectional view of two copper vessels (four were used) A A, filled with water at H H by atmospheric pressure from the well R. The heat of the sun expands the water in A A and forces it up the pipes I B about 5 or 6 feet. To increase the effect of the sun, "burning lenses," L L L, Fig. 57, were introduced, which raised the water much higher than before. The acting force is steam and air compressed in A A until their power exceeds that of the atmosphere acting on the water in R. With a fire instead of the sun, these would have been useful water-raising engines.

There exists, therefore, no good grounds to discredit the testimony of those who describe scenes often deemed fabulous, since our own "wizards" prove how readily the eye fails to detect artifices confessedly practised. Neither need it excite much surprise that nations had faith in a mythology at once sublime and awe-inspiring, and commanding the services of such clever priests and skilful mechanicians. For a good-sized engine was not only equal to gently pouring out wine, but might in one instant be made to eject the steam or water amongst or against any refractory wor-

shippers, as is supposed was done by Archimedes to defend Syracuse.

FIG. No. 58.



Single-acting Altar-Engine as a Crane.

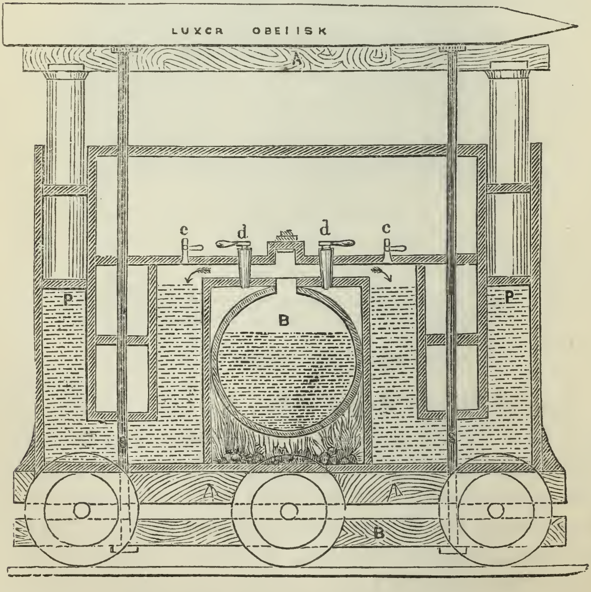
Altar-Engines as Cranes.—Fig. No. 58 is a crane nearly identical in its form to Hero's 11th invention (which is a water-raising engine), but mounted on wheels for conveying materials from place to place. B the boiler, S the steam-pipe, W the water cistern, and S S the water elevation pipes. This is the altar hot air engine as shown by Hero. Now if we place a piston P in each tube S, and connect them together at the top by a platform A, from which another platform D is suspended,

we have evidently a crane of great power and simplicity. For as air or steam admitted into the cistern forces the water up the pipes, so would any weight be lifted, within the limit of the crane power.

By opening the small cock *c*, weights could also be lowered by allowing the force to escape more or less rapidly, as required; in short, raise or lower weight with as much delicacy as is now done by any crane.

On the lowest platform a block or load could be readily placed from the ground, then raised one lift of the crane and blocked up for another lift, and so on until the required height was gained.

FIG. NO. 59.



Double-acting Altar-Engine as a Crane.

Fig. 59 is a six-wheeled steam-crane on the plan of the wine libation engine Fig. 52, but with the steam-pipes from the top of the boiler, as they are not required to be concealed as in the altar-engine. The same letters apply as in Fig. 55. By this means still greater delicacy in raising blocks to any angle is obtained, by admitting steam to or from each separate syphon-shaped cylinder as required. With such cranes, the most ponderous monolinths, even the great sphynx itself, would be readily handled or removed.*

The destruction of Assyrian, Babylonian, Chaldean, and Egyptian power also annihilated their acquired knowledge and mechanism—a great loss to mankind.

The use of steam for religious and other professional purposes appears to have made its power a secret known only to the initiated, until the republication of Hero's treatise, in 1547, set in motion that mental power which step by step has made

* These cranes were engraved before seeing the sculptured outline of the 4 and 6-wheeled besieging engines of the Assyrians in the Nimroud Gallery of the British Museum, which embody a similar idea of power to work the highly-inclined battering or rather excavating arms, and of portability by wheels. Since such engines were employed to destroy edifices, by a slight modification they could also aid in erecting them, although it is the usual opinion that inclined planes, rollers, and man-power were the chief lifting resources of the ancients. This opinion is, however, scarcely consistent with their known scientific and practical resources, as exemplified by modern researches.

For special occasions, as in Mr. Layard's case, inclined-planes or other expedients might be adopted, and from their contrast to the ordinary means be similarly delineated, yet as little represent the mechanica resources of the ancients as those employed in removing the Nimroud sculptures did those of Great Britain.

The efforts of commentators to explain down to their own ideal of ancient knowledge the plainest references to skilled productions by Moses, Homer, and others, ill accord with the results of discovery; and —space permitting—on the article on wheels a few examples of this class will be noticed, in support of the literal accuracy of the texts called in question, and of the mechanical skill of past ages.

the steam-engine what it is, and which is now experimenting with hot air on a large scale in America.

Anthemius, 530.—In revenge for having been baffled in a wordy dispute by Zeno the orator, this architect of Justinian conveyed steam by elastic pipes below the floor of Zeno's house, and so alarmed the orator that he yielded to a rival who shook his house and the "earth as with the trident of Neptune." It is thus clear that Zeno had no knowledge of steam power, so familiar to his professional opponent.

Gerbert, 1125.—This learned priest appears to have applied one of Hero's plans to an organ at Rheims, in which the air, escaping by the force of heated water, produced musical tones in combination with water.

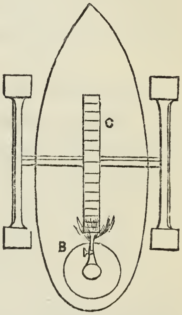
Alberti, 1412.—The knowledge of the extreme force of steam again appears professionally by Alberti comparing it, when generated from water in the cavities of limestones, as bursting them with great noise, and blowing up the kiln with irresistible power.

De Garay, 1543.—Spain being in the meridian of her power about this time, transporting her armies across the ocean, became an object of great importance, when De Garay, one of her naval captains, proposed to propel ships by steam. The Romans transported Claudius Caudex's army into Sicily by paddle-wheel boats worked by oxen; and in 1472, Valturius describes two paddle-wheel galleys. The one had five wheels on each side, and each opposite pair connected together by a cranked axle. These cranks were again connected together, that the motion of the paddle-wheels might be simultaneous. The other boat had only one paddle-wheel on each side, fixed on a cranked axle.

Acquainted, probably, with this or earlier Homeric ideas or modes of moving ships, and ambitious to emulate the Romans,

or, Joinville-like, invade our own envied shores (as was attempted by the Spanish Armada, in 1588), De Garay selected steam as his auxiliary. His plan was kept secret, but a steam-boiler was on board, and the paddle wheels were seen to propel the vessel. It might be done by a rotatory steam wheel, like Hero's, on the paddle shaft, or by a steam jet driving a central wheel, as in Fig. No. 60, or by a steam jet issuing at the stem against the resisting water, but below its surface. The result of a trial at Barcelona, before the Spanish court, was that a vessel of 200 tons burden was propelled about three miles an hour—no mean performance then—and now interesting from the progress of steam navigation. De Garay's success was honoured by the court; but his invention was *neglected.*

Fig. No. 60.



De Garay's Steam Boat, 1543.

From so many modern examples of neglected inventions it is more surprising that De Garay should have received honour for a successful experiment, than that his plans were not improved upon.

The republication of Hero's treatise at Bologna, in 1547, and at several other places, led many eminent men to suggest various modes of usefully employing steam and hot air, a few of which will be noticed.

About 1548 Vitruvius refers to the steam from an æolipile as wind produced by heat; and Philibert de l'Orme proposed an æolipile to cure smoky chimneys.

Cardan, 1557.—The force of steam, and the rapid vacuum produced by its condensation, are both ably treated by Cardan, who also invented the smoke-jack, as still made, to illustrate the power of hot air. Possessing great scientific and superstitious knowledge, his life presents a singular blending of

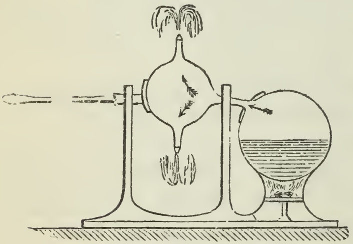
these together; as was also partially displayed in England by the Marquis of Worcester and other inventors.

Bressen, 1569.—An anonymous pamphlet, published at this time, on the expansive force of steam, is attributed to the pen of this celebrated mathematician and reputed author of a collection of machines, but published in 1578, after his death.

Matthesius, 1571.—In a sermon Matthesius illustrated the great effects produced by small things, by reference to the great power produced by heat from a small quantity of water.

And in 1577, an observer in Soyer's useful *cuisine* department introduced a rotatory steam-engine, Fig. No. 61, to turn a roasting-spit, as a great and *clean* improvement upon the dog, previously employed to do so, but not always proof against "pawing" the savoury temptation beside him.

FIG. No. 61.



Roasting Engine, 1577.

In 1578, an English military writer, and in 1587, Pancerollus, both refer to paddle-wheel vessels as then in use.

Ramelli, 1588.—At this time another collection of machines was published yb this experienced engineer, which, along with that of Bressen, greatly promoted subsequent improvements in steam and other machinery.

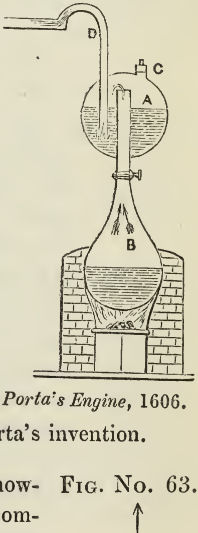
Platte, 1594.—Sir H. Platte still describes steam as "water attenuated by fire into air," which by its emission from a whirling æolipile, made of copper, blows a fire strongly.

He also suggested the collection of steam from domestic

operations, and conveying it by pipes to force the growth of plants in a house near the kitchen.

Porta, 1601—1609.—Porta's plan of showing the relative volume and force of steam in raising water, was an ingenious one for his time.

Fig. No. 62.



Porta's Engine, 1606.

The neck of the boiler B, Fig. No. 62, rises above the water in the vessel A, so that the steam generated in B may force the water out of A up the pipe D. The pressure of the steam was ascertained by weights on the valve C, and its relative volume by the ratio of the quantity of water forced out of A to that evaporated in B to force it out. Although not an accurate plan, still it shows a clear idea of obtaining that knowledge of steam which has so much engaged the attention of modern philosophers, as already explained, and was given by Porta as an improvement on Hero's fountain, Fig. No. 53. The popular magic lantern is Porta's invention.

Fig. No. 63.

Rivault on the Force of Steam, 1603.

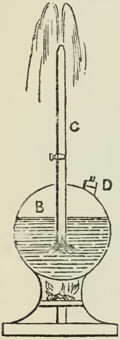
Rivault, 1603.—Rivault shows a knowledge of the great force of steam, by his comparing it as equal to burst a bomb partially filled with water and placed on a fire, as in Fig. No. 63. The abutment or point of resistance to the escaping steam being in a line opposite to the fracture, the burst shell would be carried in that direction, as indicated by the arrow. Likewise, in any explosion of steam, the boiler would be forced in a line opposite to the fracture.

S. De Caus, 1612—1615.—There appear to have been two

De Caus's—a Solomon, the eminent engineer, and an Isaac, also a steam-engine historian. Solomon still describes steam as "water dissolved into air by fire," and its force as "infallibly bursting a copper ball containing water and exposed to heat."

He also discusses the evaporation of water by heat, and the condensation of such vapour by cold to its original volume of water again.

Fig. No. 64.



De Caus's Engine, 1612.

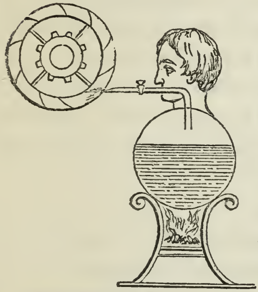
Fig. No. 64 shows his plan of raising water. As the steam is generated it forces the water below it at B up the pipe C. The pressure of the steam is regulated by the valve D, at which also the boiler was filled. For raising water, his plan is inferior to Porta's in economy, since the hot water is expelled from the boiler, losing both time and heat in generating steam again. Porta's, on the contrary, forces cold water from a separate vessel, and retains the hot water for steam, a difference greater, yet not much dissimilar to Newcomen's condensing in the cylinder, and Watts's condensing in a separate cylinder.*

Ramsay, 1618.—In 1618, David Ramsay obtained a patent for a new engine to plough without horses or oxen, to raise water and propel ships without sails; also in 1630, to raise water by fire from deep pits, move ships against wind or tide, and to fertilize the earth. We have not met with any lucid description or sketches of Ramsay's early ideas of ploughing, pumping, or sailing by steam or other motive power. Two out

* De Caus's sun-fountains are given, page 228, as illustrating the effect of the sun on water in idols.

of the three have been fully realized, and Lord Willoughby is now ploughing by steam at Grimsthorpe.

Fig. No. 65.



Branca's Engine, 1629.

Branca, 1629.—In his mechanical treatise, this distinguished physician describes a rotatory steam-engine he used for grinding his drugs. He gives the top of the boiler the form of a man's head with a pipe in his mouth, blowing a jet of steam against the arms of a wheel D, Fig. No. 65, to cause it to rotate on its axis, and by the pinion C give motion to the drug machinery.

A modification of this plan was recently tried at the Surrey Docks, with a wheel 11½ feet diameter, making 500 revolutions per minute. But the consumption of steam for an equal duty being greater with the rotatory than with a piston engine, led to its disuse.

Branca also describes a hot air rotatory engine, driven by the heat and smoke collected from a smith's forge, whereby to aid the smith in his operations; but all these engines he gives as the invention of others and not his own.

Drebbel, 1630.—The sounds emitted by the ancient idols are said to have been successfully imitated by Drebbel; introducing a little moisture with the air, their mutual expansion by the heat of the sun produced a "soft and pleasant harmony." This is closely following some of Hero's singing-birds illustrations, where the expansion of air by heat performs a chief part, aided by steam when required.

Beaumont, 1630.—Wood informs us that this enterprising gentleman expended about 30,000*l.* on introducing tramways

amongst the Newcastle collieries. Their ultimate success led to modern railways, now exercising so vast an influence over the civilized world by means of the locomotive power of steam. This power it is our object to popularly explain; but it will be more generally instructive to trace the gradual improvements of the steam-engine, until the locomotive drops in as a young and powerful branch of an ancient family.

In 1632, amongst several other inventions, Thomas Grant included moving ships without sails; and in 1640, Edward Ford also proposed to move ships against wind or tide by some great power not clearly defined.

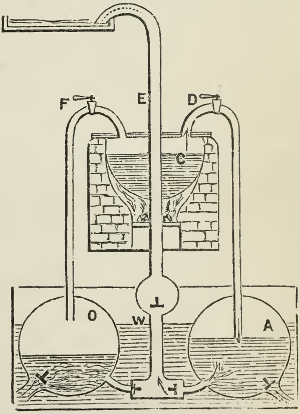
Wilkins, 1648.—In a contest of wit with the Duchess of Newcastle, Bishop Wilkins, besides other ingenuities, suggested the possibility of flying by "high pressure" steam moving large wings, which has been more than once attempted in modern times.

Marquis of Worcester, 1651—63.—On the fall of Charles I. in 1648-9, the Marquis fled to the continent, where he remained until 1656, when he returned secretly to London for Charles II., but was taken and imprisoned in the Tower. At the time of his exile, Hero's treatise had gone through five editions, besides the treatises of others already referred to; and when so much attention was directed to motive engines, it was likely to arrest the noble exile's notice when abroad. It is probable that from these sources most of his ideas originated, as afterwards given in his letter of 1651 to Hartlib, and in his hundred inventions of 1656.

In his writings and prayers, he thanked God for showing him "so great a secret of nature, beneficial to all mankind," yet he studiously withheld from mankind the construction of his "semi-omnipotent power," leaving it to be considered as a steam engine.

When a political prisoner in the Tower of London, this celebrated nobleman—after the example, but without the clear illustrations of Hero—drew up "The Century of Inventions." Of these the 68th refers to the steam-engine "as an admirable, most forcible way to drive up water by fire, which hath no boundes if the vessels be strong enough." He also compares the force of steam to the bursting of a cannon, evidently then, as it still is, a popular expression for a great force. No drawings or description of his engine have been found in this country; but in 1656, the Duke of Tuscany saw an engine lifting water 40 feet high, at Vauxhall. To the perplexity of readers, different authors have differently embodied the Marquis's description. Stuart and Galloway show a double De Caus engine, whilst Millington and Tredgold sketch a double Porta's engine, as in Fig. No. 66, where the steam from the boiler C passes down the pipe D, to expel the water from A, whilst O is filling with water at L, from the well W. The valves all open only one way, as in the sun-fountain. The cock in D is then shut and F opened, that the steam may expel the water from O up the central pipe E, whilst it is refilling again, and so on alternately to keep "one forcing whilst the other is filling," agreeably to the text.

Fig. No. 66.



Worcester's Engine, 1656.

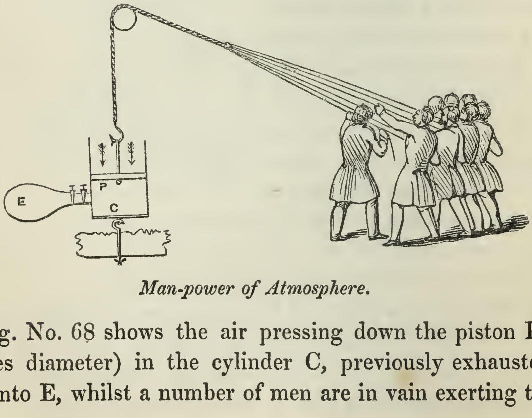
The Marquis also proposed to move ships by paddle-wheels against the wind or stream; but it is much to be regretted that he left no tangible evidence of his designs, such as is done by those preceding him in their illustrated works.

FIG.
No. 67.

Atmosphere raising water.

Otto Guericke, 1654.—This able man records some valuable experiments which illustrate the pressure of air in raising water, or in depressing a piston. In Fig. 67, the pressure of the air on the water in C is forcing it about 30 feet up the pipe A, previously exhausted of air, into the receiver E. If the vacuum had been perfect it would, as previously explained, have risen nearly 34 feet high.

FIG. No. 68.

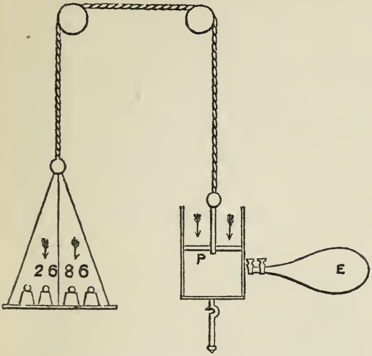


Man-power of Atmosphere.

Fig. No. 68 shows the air pressing down the piston P (17 inches diameter) in the cylinder C, previously exhausted of air, into E, whilst a number of men are in vain exerting them-

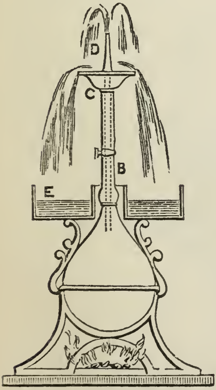
selves to prevent its descent. Fig. No. 69 shows the pressure exerted balanced in a scale by 2686 lbs. The area of a 17-inch piston being nearly 227 square inches, gives 11·8 lbs. per square inch, or nearly the same as is obtained in a Watts's condenser. If the vacuum had been perfect, the pressure would have been 14¾ lbs. per square inch.

FIG. No. 69.



Weight power of Atmosphere.

FIG. No. 70.



Kircher's Engine.

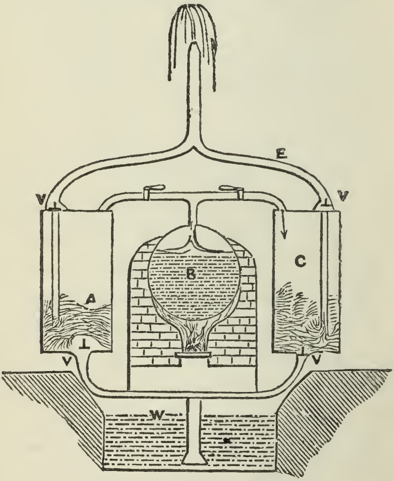
Kircher, 1656.—Kircher's illustration of Porta's plan might be made a pretty little fountain, by receiving the falling water in a cistern fitted round the stem B, and raised by atmospheric pressure to refill C again, as Fig. 70. He also suggested an improvement on Branca's engine, by having a blast of steam on each side of the wheel at the same time; and his models are highly spoken of as the workmanship of a mechanic named George De Sepi.

Jack of Hilton, 1658.—"Jack" is described as an artistic ælopile, resembling the human figure, with his right hand on his head, and his left hand "on pego," to blow the

fire in Hilton Hall, whilst the Lord of Essington drove a goose three times round that fire before it was roasted for the Lord of Hilton, celebrated in Godiva procession annals.

Sir S. Morland, 1670—85. This distinguished mechanic wrote an essay (now in the British Museum) on the "Weight and Measure of Water elevated by Machines." His plan was by alternately filling and emptying two or more cylinders 30 times (or strokes) per minute. The duty he estimated by the weight raised in a given time, as is still done in this country. No drawings of his engine have come under our notice, but

FIG. No. 71.



Morland's Engine, 1680.

Fig. No. 71 embodies the description given of one with two cylinders. On steam passing from the boiler B to the cylinder C, it expels the water up the central pipe E, while A is filling with water from the well W, to be emptied in like manner whilst C is filling, and so on alternately. The relative volume of steam to water he gives as about 2000, and its

force as capable of "splitting a cannon;" but being regulated by "statics and science to *measure, weight,* and *balance,*" it bears its load peaceably like a good horse, and becomes of great use to mankind.

He gives the following proportions of cylinders, and the weight of water they would raise each stroke. We have added the height in inches of the water raised equal to the diameter of the respective cylinders.

CYLINDERS.			WATER RAISED EACH STROKE.	
				Height in each cylinder.
No.	Diam.	Length.	lbs.	Inches.
1	1	2	15	3·7
1	2	4	120	7·4
1	3	6	405	10·0
1	4	8	960	14·7
1	5	10	1875	18·3
1	6	12	3240	22·0
2	6	12	6480	22·10

and so on to 90 cylinders, each lifting 3240 lbs. or 291,600 lbs. of water raised a considerable height per stroke. There can, therefore, be no doubt of Morland's clear appreciation of the nature of steam, and the method of estimating its performances. In 1675, he raised water from the Thames 60 feet above the top of Windsor Castle, at the rate of 60 barrels per hour, by eight men, which gave so much satisfaction, that in 1681 the King presented him with his medallion portrait set in diamonds.

In 1678, Bushnel proposed to propel ships by oars bound together, and the rope ends fastened to the capstan, to be wound off and on alternately for each stroke of the oars, as afterwards tried by Fitch in 1788 with steam-power.

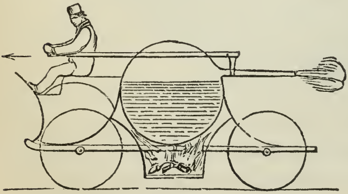
Hautefeuille, 1678. — This learned abbé and mechanist gave designs of engines for using heat, steam, gunpowder, and alcoholic vapour as motive agents. One plan was by direct

pressure of steam or hot air on water; another by condensing the steam or vapour below the piston, to produce a vacuum for the atmosphere to force down the piston, as in Fig. 70; and a third was by exploding gunpowder on alternate sides of a piston.

With steam, Savary and Newcomen effected the first and second; but the third has not yet proceeded beyond experiment. A recent trial of gunpowder as a motive power, at Swindon Station, by James Squires—an ingenious mechanic and electric experimenter there—indicated that, as in shooting, the *débris* of the powder speedily choked up the moving parts, and arrested the engine. It was tried by fitting a separate powder-chest at each end of a small cylinder boring engine, and the powder was regularly admitted by a valve, and exploded by galvanic agency. The action was impulsive and not sustained, which, along with the deposit from the gunpowder, discouraged further trials.

In 1681 the Prince Palatine Robert's boat, propelled by revolving oars on the Thames, beat the King's 16-oar boat by a long distance. Papin was present at this trial. In 1682, a horse paddle-wheel boat was employed at Chatham for towing ships.

Fig. No. 72.



Sir I. Newton's Locomotive, 1688.

Sir I. Newton, 1680.—In his "Explanation of the Newtonian Philosophy," Sir Isaac Newton shows the elastic force of steam, by its locomotive capabilities, as Fig. No. 72, where the globular boiler B, with its steam-jet-pipe and cock C, is mounted "upon little wheels, so as to move easily upon a horizontal plane; and if the hole be opened, the vapours will rush out violently one way, and

the wheels and the ball at the same time will be carried the contrary way." This is the first idea of steam locomotion we have met with.

The principle of producing locomotion by the velocity of one fluid acting against a fluid comparatively at rest has formed the subject of a patent by Allen in 1724, Rumsey in 1788, and Gordon in 1845. It was also the plan of Matthesius's roasting engine, Hero's rotatory engine, and various other inventions since that time.

Papin, 1680—1707.—This eminent physician and engineer proposed to apply steam to various purposes. Amongst others to dissolve bones, to throw bombs, to drive machinery, to propel ships, and to raise water. In his celebrated "Steam Digester" for dissolving bones into useful food, he employed steam of a temperature equal to melt lead, or about 612°. This indicates a pressure of about 1400 lbs. per square inch, which would propel either balls or bombs with very great force; for Perkins's celebrated steam-gun of 1838-9 only used steam of 410° Fah., or 450 lbs. pressure per square inch. To regulate the force of the steam in the digester he invented and employed the steelyard safety-valve C, Fig. No. 73. The lever C is jointed at one end to the valve seat, and the fulcrum is jointed centrally with the safety-valve on which it rests. The weight *a* presses the valve down by the fulcrum with more or less force proportioned to its distance from the centre of the valve. This valuable invention is still used in steam boilers in its original plan, although various similarly-loaded levers with shifting weights are shown in Hero's ancient designs.

In 1687, at Marbourg, Papin constructed an atmospheric engine for raising water to drive a wheel, which also worked the air-pumps used for producing a vacuum in the long mine pipes, below the piston, as in Otto Guericke's experiments.

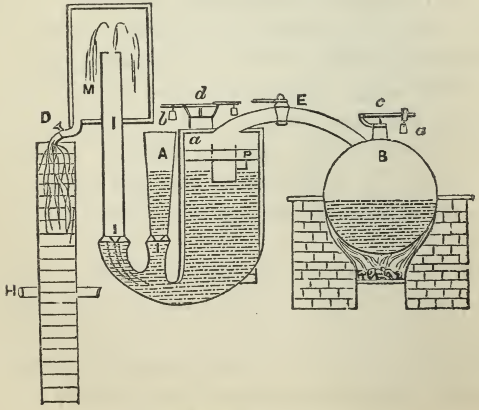
To render the action continuous, two cylinders were joined together by a two-way cock, which alternately opened each

cylinder with the air-pump and the atmosphere. Each piston was connected by a rope to a shaft to give it motion, but the ropes were wound round in contrary directions, so that as one was raised the other was depressed; an arrangement adopted afterwards by Leupold for high-pressure steam.

Like that of the late promoters of the atmospheric railway, Papin's difficulty arose from the slowly obtained vacuum and leakages, which he failed to overcome.

His numerous experiments showed him the advantage of a good vacuum below the piston, which he sought to obtain in various ways; amongst others, by the explosion of gunpowder in the cylinder. This he abandoned as dangerous, and proposed to raise the piston by the steam, and then to condense it, that the air might depress the piston against a vacuum. He did not carry this out, but it was successfully done by Newcomen. Savary's success in England led the Elector of Saxony to recommend Papin to abandon his own superior proposal, and try Savary's plan. Fig. No. 73 is an outline of the result, which Papin calls the Elector's Engine.

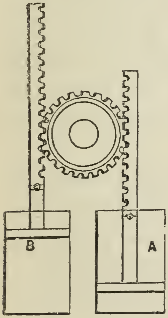
FIG NO. 73.



Papin's Engine, 1704.

Steam from the copper boiler B passes by E to the cylinder C and presses down the floating piston P, to force the water up the pipe I into the cistern M. The cylinder safety-valve was then opened to admit the steam to escape, and the water from the mine, aided by the air vessel A, refilled the cylinder again.* For driving machinery a water-wheel was added and the cistern M made air-tight. The outlet pipe D being smaller than the inlet pipe I, the air acting with the water was compressed and aided in keeping up a uniform force to turn the wheel H and produce a regular rotation. Even down to Smeaton's and Newcomen's time, this was an approved mode of rotation when available.

FIG. No. 74.



Papin's Marine Engine.

For steam-ships he employed two or more cylinders, A B, having racks jointed to the piston rods, and arranged to gear alternately into the central pinion, P, on the paddle-shaft, and produce rotation. Several modifications of this plan were tried before the crank came into general use.

Papin first systematically tried to save fuel by improved boilers. One form was bent like a syphon, with the fire in the short end, and the draught down through the fire, whilst the cylinder was fixed on the long end, so that the heat acted on it in its passage to the chimney. The fire-bars were, however, so quickly destroyed by the intense heat, that it was called the "little volcano," and probably led Papin to recom-

* Air vessels are now used with much advantage in the construction of pumps for ordinary and locomotive use.

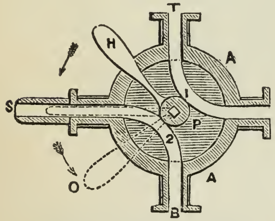
mend hot air for reducing mineral ores, as successfully done by Nelson in the present century.

Another boiler was 8 feet by 5 feet, with a tubular flue 24 feet long by 10 inches square, bent so as to pass four times through the water. This gives a heating surface of about 80 square feet, and led to a saving of about 75 per cent. of the fuel then used for ordinary boilers.

Although an account of this boiler, and other novel machines by Papin, was published in 1695 by Cassell, yet it appears not to have been known to Savary or Newcomen, since they used inferior boilers for their engines.

Fig. No. 75 is a sectional view of the useful and ingenious two-way cock of Papin, but usually called a four-way cock from the four external openings in the outside socket A A. The central plug P is fitted steam-tight into the socket A A, like an ordinary cock-plug, but has two passages 1, 2, through it, which alternately connect each adjoining pair of external openings, or shuts them all, as the plug is moved by the handle H one-eighth or one-quarter turn.

Fig. No. 75.



Papin's Two-way Cock.

For a double-acting steam engine the passage S B leads from the boiler below the piston, and the passage T C from the top of the piston to the condenser, or to the atmosphere in high-pressure engines. By moving the handle H to S the passages are all shut; but when moved on to O, the boiler is connected by S T to the top of the piston, and the condenser by C B below the piston.

To equalise its wear, Bramah improved its form, and made the plug turn quite round within the socket.

It is thus seen that several important inventions and valuable suggestions, since reduced to practice, are due to Papin.

In 1699, boats propelled by revolving oars were tried both at Marseilles and at Havre, by M. Daguet, which were favourably spoken of.

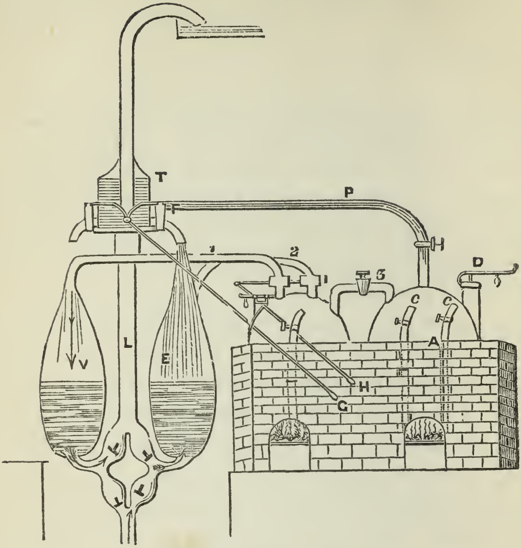
Amonton's Hot-air Rotatory Engine, 1699.—This was an ingeniously arranged box-wheel, 12 feet diameter, fitted with 36 air-tight cells, of which the 12 inner ones had valves opening upward only. In the lowest four of these valved cells were 750 lbs. of water, which was forced up one side by hot air, that its unbalanced gravity might give a downward motion to the wheel and produce rotation.

The action was by a tube conveying the hot air from each outer cell to each third lower water cell, to force its contents up through the valve in rotating, and as the wheel revolved its lowest edge passed through water to condense the rarefied air again. The fire was placed in a confined channel, to act directly on the outer air cells, resembling the position of a breastwater wheel; but instead of the downward water-flow, there was an upward hot-air action, yet both produce a similar rotation downward by the gravity of water.

The heat given out to the water by the hot air was thus lost, which in Ericsson's hot-air engine is mostly recovered, by exhausting it through wire gauze, and passing the cold air through this heated gauze to re-absorb the heat from it.

Savary, 1698—1702.—The great energy displayed by Savary in improving and introducing steam-engines added much to their popularity in England. His first engines were nearly the same as those already described, with the addition of cold water poured over the cylinder to produce a more rapid vacuum in it, but which had the bad effect of cooling it each stroke. He next improved the steam-admission valves, the mode of opening them, and his boilers.

Fig. No. 76.



Savary's Engine, 1702.

In Fig. No. 76, the two boilers are connected together by the pipe 3, and have gauge-cocks, C C, to ascertain the relative height of the water in them. The largest boiler, A, is filled from the water-tank T, and the small boiler is supplied with steam and hot water from A. The steam-pipes 1, 2, from B, convey the steam alternately to the vessels E V, to expel the water in them up the central pipe L, as in Morland's engines. When one of these, as E, has been emptied the cock F is opened by the handle G, and cold water poured over the vessel to condense the steam in it, and in like manner with V. The handle H conveniently regulates the steam-valves, and G the injection-cocks. One of Papin's safety-valves, D, regulated the force of the steam in the boilers.

It is related that Savary accidentally discovered the force and condensation of steam from a wine-flask—not quite empty

—being thrown on a fire and producing steam, when he took it off the fire and immersed its mouth below cold water, which condensed the steam and filled the flask by atmospheric pressure.

The labours of Worcester, Morland, and others in England, had so publicly shown the capabilities of steam, that in all probability Savary was fully aware of its force; but such an incident might suggest the mode of condensation he adopted, and which, applied internally, still exists.

Savary states:—"My engine raises a full bore of water 60 or 70 feet high, and, if strong enough, I would raise you water 500 or 1000 feet high."

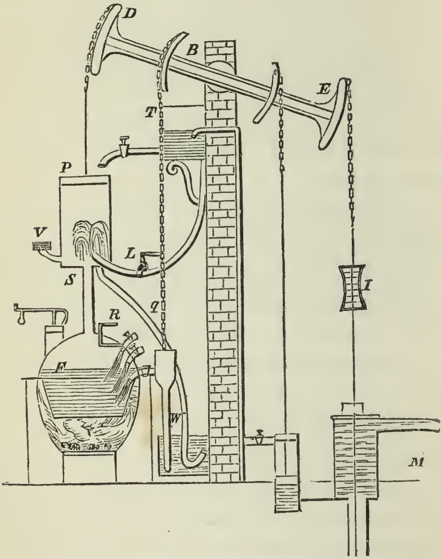
Only in the improved boiler and valve arrangements do Savary's engines exceed the idolatrous one, since the action of both is similar in passing from the boiler to two separate vessels, and expelling their contents out by other pipes.

Savary also proposed to propel ships by paddle-wheels worked by the capstan and suitable connecting ropes, which the Lords of the Admiralty referred to their surveyor, Mr. Dummer, who, like Sir W. Symonds in 1837, on Ericsson's screw-propeller, reported against Savary. Still unsatisfied, he persevered, until one of the commissioners thus faithfully expressed the sentiments of many in authority besides Government officials: "What business have interloping people, that have no concern with us, to pretend to contrive or invent anything for us?"

Newcomen's Atmospheric Engine, 1705—1720.—The exertions of Papin and Savary to bring the steam-engine into general use for draining mines stimulated others on in the same path, and amongst these Newcomen, a country blacksmith, honourably distinguished himself by his decided improvements on the steam-engine. Hitherto the air had only been used to fill the water-vessels, but on the principle, so clearly laid down by Otto Guericke, Newcomen employed the

air to perform the principal duty, and steam only as an auxiliary. He also introduced the beam or balance lever, D E, Fig. No. 77, freely suspended on its centre, B. The piston P

FIG. No. 77.



Newcomen, 1705—1720.

was kept tight by a little water on its upper surface from the tank T, and was attached by a rod and chain to D, whilst a common lifting-pump M, leading to the mine, was attached to the end E. The cylinder was placed over the boiler F, and as the steam raised the piston, the counterpoise weight I lowered the pump-rod and bucket down through the water. The injection-cock L is then opened, and water admitted to condense the steam in the cylinder. The air passed out by V, and the condensed steam and injection water by the pipe Q, to the

hot well W. Watt's principal improvement consisted in placing his condenser in the position of the hot well, and condensing the steam there in place of in the cylinder. By thus condensing the steam below the piston, Newcomen obtained a good vacuum, and the pressure of the air on the piston forced it and that end of the beam down, whilst the elevation of the other end raised the water from the mine. Steam was therefore only employed to raise the piston, and air to do the duty.

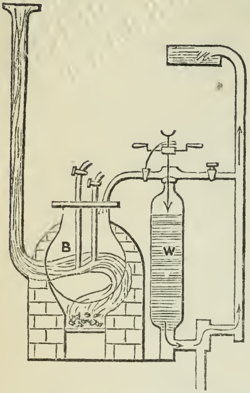
At first, Newcomen adopted Savary's plan of external condensation, but a faulty cylinder having admitted water internally, the condensation was more rapid, with increased effect from the engine. Since that discovery, internal injection has generally but not always been adopted.

The various cocks and valves were all opened by hand until Potter, a young lad attending one of the engines, ingeniously connected them to the beam by strings and catches, so as to open them with much regularity. Improved connections succeeded his temporary ones; still to Potter the credit is due of introducing the self-acting hand-gear.

The beam, the pump, internal condensation, and self-action were important additions to the previous steam-engines, earning for Newcomen and his assistants a well-deserved fame. We rejoice, therefore, to observe that it is intended to raise a suitable memorial for him in his native locality.

Desaguliers, 1717, 1718.—This learned doctor gave his preference to Savary's engines, and states that one erected at Petersburgh raised 2520 lbs. of water 40 ft. high per minute; and that another raised water 53 ft. high when making six strokes per minute, but only 35 ft. high when making nine strokes per minute. He also contended that they were more economical and effective than Newcomen's; stating that one of his engines, which cost 80*l.*, raised 370 lbs. of water 38 ft. high, while one of Newcomen's, which cost 300*l.*, only raised

Fig. No. 78.

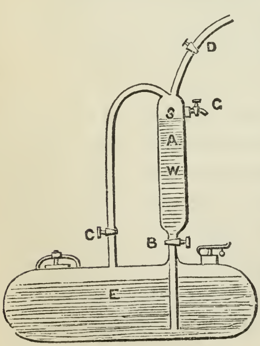


Desaguliers, 1717.

150 lbs. per minute. Fig. No. 78 is an outline of Desaguliers' engine with its improved arrangement of boiler-flues; B the boiler, W the water, M the pipe to the mine. The action is similar to Savary's, but single acting.

Desaguliers' comparative statement merits some notice, since there was a constant loss of heat and time from Newcomen's chilled cylinders, amounting to about 30 per cent. of the whole steam generated. This source of loss would be little felt in Desaguliers', since water only slowly absorbs heat downwards. The following experiment, made by Goldsworthy Gurney, Esq., in September, 1850, at Westminster, in presence of several engineers, bears on these points, and may be instructive. Steam of 20 lbs. pressure above the atmosphere was alternately admitted in contact with cold water in the boiler-feeder A F, and in contact with air between the steam and cold water. Fig. No. 79 is a sketch of the boiler and feeder on which the experiment was made. It is used by Mr. Gurney for his steam-jet plan of ventilation in the law courts, so highly spoken of in the House of Lords. As no machinery was required, the boiler was supplied by water without a pump. The water-feeder, A, W, S, was connected to the boiler by the pipe B, and to an elevated water-cistern by

Fig. No. 79.



the pipe D. When it was filled D was shut, and B and C opened, that the steam might pass to the top of the water, and balance upward pressure below in B. The water then descends by its own gravity into the boiler.

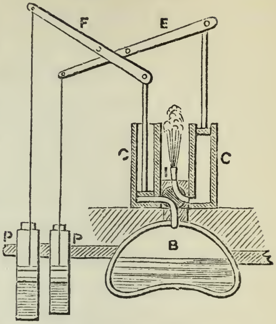
When this feeder was partially filled with cold water, then air, then steam, cut off from the boiler at C, the air appeared to slowly absorb heat from the steam ; but when the air was expelled at G, and the steam remained in contact with the water, no perceptible absorption of heat from the steam took place. Even after this isolated steam had remained ten or twelve minutes in contact with the cold water, it blew off at G with much force. It was the difficulty of quickly condensing the steam which had done its duty, and not the condensation of the steam forcing the water, which retarded the action of these engines. Internal condensation was more rapid, but entailed the loss from a chilled cylinder each stroke. Besides, the unbroken surface of water rising up slowly against the steam would compress it and increase its force, as it does in the "back pressure" of a locomotive engine. Forcibly injecting broken water like rain amongst steam is a very different process, yet requires eleven times (or more, according to temperature) as much water to condense the steam as to generate it.

Beighton, 1718.—Potter's hand-gear was still further improved by Beighton, so as to open and shut all the valves and cocks with much precision. He also widened the top of the cylinder to prevent the water on the piston flowing off, and conveyed it by pipes to the boiler, or hot well, as it became hot. The action and arrangements of cylinder, beam, and pump were similar to Newcomen's.

Leupold, 1720.—Leupold recalled attention to high-pressure steam-engines by a very simple yet effective double-acting engine, Fig. No. 80. The steam generated in B passes alter-

nately by the two-way cock I, to the cylinders C C, and raises the pistons connected to two beams which work the lifting-pumps P P, as in Newcomen's plan. A turn of the cock opens a passage for the steam to the atmosphere from one cylinder, and from the boiler to the other cylinder at the same time. The piston end of the beams are heaviest, to balance the weight of the pumps, that the pistons may descend by their own gravity.

Fig. No. 80.



Leupold, 1720.

This is given by Leupold as an improvement on Papin's atmospheric engine, similarly arranged.

Newcomen raised the water by atmospheric pressure during the downward stroke, but Leupold did so by steam pressure during the upward stroke of the piston, and the simplicity of this engine has rarely been surpassed.

Leupold also proposed an improved form of Amanton's hot-air rotatory, by using tubes instead of valves to connect the water-cells, which were also placed much nearer the periphery of the wheel to give greater effect to the raised water.

In 1724, John Dicken, and in 1729, John Allen, proposed engines to raise water, or move mills and ships. Allen's ship-propeller was by a jet of water or other fluid forced through the stern of the vessel below the surface of the water, whose resistance moved the vessel in a contrary direction, as in Sir Isaac Newton's locomotive-engine. This idea has been since tried by Fitch, in 1788, with water, and by Mr. Gordon, in 1846, by hot air, on the Thames.

Allen expressed his decided opinion in favour of a steam propeller of some sort as preferable to paddle-wheels, and more of the nature of the fish-tail propulsion.

To economise fuel with rapid generation of the steam, Allen

proposed a fire-box boiler with a spiral flue through the water, and a bellows blast, to urge the " sluggish vapour" through the tube, as was done in Ericsson's Novelty Locomotive of 1829.

Gensanne, 1730.—By the gravity of water and the impulse of a falling weight, Gensanne made the steam-valve and injection-cock self-acting. On each end of a lever fitted to the water-cistern were water-buckets with a valve in the bottom, and in the cistern were also valves which the buckets opened, so that as one bucket was filled and descended by its gravity the other was emptied and ascended.

The bucket-valve was opened by the gab or fork of a bell-crank lever, which had a weight on its vertical end, and on beginning to ascend, the weight, or "tumbling-bob," was set at liberty, and the fork gave a smart jerk to the ascending levers.

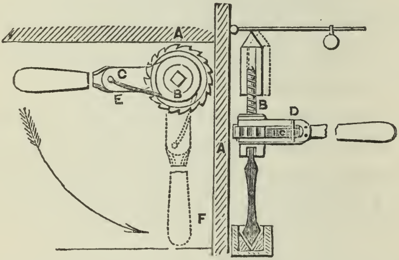
The motion thus obtained was conveyed by another lever and parallel side-rods to open the valve by a gab or fork, and the injection-cock by a slotted lever, at the proper times. This is the first "gab" motion we have met with for working valves.

M. de Moura also constructed another self-acting apparatus of this class, but using a floating copper ball to give a motion outside corresponding to the rise and fall of the water in the receiving-cistern.

Jonathan Hulls, 1736.—We have seen that various modes of propelling ships by paddle-wheels or revolving oars had been proposed, using steam or other power to move them. In 1736, Hulls made a vigorous effort to apply a single-acting steam-engine to propel ships. This plan was to produce rotation by ratchet-wheels aided by a weight, whereby to move a central paddle-wheel in deep water, or two

poles alternately thrust against the ground by a double-crank axle in shallow water. As the ratchet motion was much used until superseded by the crank, fly-wheel, and double-acting cylinder, its action will be explained by its modern adaptation to a very useful boring-brace in all confined corners, where a cranked-handled brace could not be turned round.

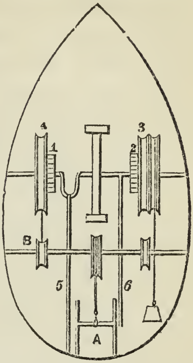
Fig. No. 81



The ratchet-wheel A, Fig. No. 81, is fixed on the boring-spindle B. The detent or catch C is jointed to the handle D, and kept against the ratchet by the spring E. The handle moves freely round B towards A, without moving it, in the direction of the angle of the ratchet teeth, as the detent has no bite; but when moved in the contrary direction, the detent acts directly against the teeth, and carries round the ratchet and drill with it about one quarter revolution to F. The handle is then moved back to obtain another bite, and so on consecutively, but losing as much time in stopping as in rotating.

Now two handles with detents moved alternately would produce continuous rotation, and on this principle Hulls, Wasborough, and others obtained rotation from a single-acting cylinder. Fig. No. 82, shows Hulls' plan. A, the steam

Fig. No. 82.



Hulls' Steam Boat, 1736.

cylinder, whose piston is connected by a rope to the central pulley on B, and the two end pulleys by other ropes to the loose pulleys, 3, 4, on the paddle-wheel shaft, on which are fixed the ratchet-wheels, 1, 2, into which the loose wheel detents fall similar to the ratchet brace. As the air forces down the piston it moves B round one-quarter turn, and with it the paddle-shaft by means of the pulley 4, and ratchet 1. Steam is then admitted to raise the piston, when the weight W works round the pulley 3, and ratchet 2, to keep up the rotation of the paddle-shaft. In shallow water the cranked axle and pole 5, 6, were substituted for the paddle-wheel.

1739—1760.—In 1739, Belidor wrote a history of the steam-engine; and in 1741 Payne investigated the density of steam with considerable accuracy.

His spherical balloon-shaped steam-generator rested on its point, and had a vertical rotatory tube, through which water ascended to a horizontal tube above the generator, from whose ends it dropped on the top of the hot generator to produce spheroidal steam,—a plan again revived.

Experiments made at Newcastle and at Wednesbury are said to have realized the then high evaporation of 8 lbs. of water by 1 lb. of coals.

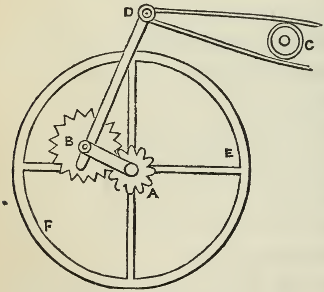
In 1740, Dr. Hale suggested and Fitzgerald tried to introduce air into steam boilers to promote economy, but their bellows were not sufficiently powerful to overcome the resistance of the steam.

In 1845, Mr. Wilkinson, and more recently Dr. Houston, have both patented modifications of this plan of combining air and steam to work an engine.

In 1751, Blake discussed the proportion of cylinders. In 1752, Bernouilli proposed an angular ship propeller on the principle of wind-mill vanes, to be driven by steam or other power: and in 1758, Emerson investigated the construction of steam-engines. In 1759, Brindley proposed stone and wood boilers, with cast-iron fireplaces and flue-tubes, to prevent loss of heat by external radiation. The bottom was of stone, and the sides and top of wood. Others were of stone or bricks, cemented together. From the internal fire copper tubes passed through the water to the chimney, as in modern locomotive boilers.

In 1757, as part of an improved plan of Papin's rotation by racks and pinions, Fitzgerald added the fly-wheel, which now forms a prominent part of fixed engines. To make it effective in regulating the velocity of the engine, it is made with light arms and a heavy rim, E F, that it may absorb power when the piston is at its greatest velocity, and give out its accumulated centrifugal force to continue the rotation when the piston has no velocity, at each turning point of its stroke. For instance, a stone swung round in a sling acquires a force which propels it beyond the limit which one unaided muscular effort of the hand and arm would have done; so, in like manner, the fly-wheel accumulates a force which continues the motion of the machinery when the piston itself could not do so. C D the engine beam, A B the sun and planet motion.

Fig. No. 83.



Fitzgerald's Fly Wheel, 1757.

In 1760, Genevas proposed a compressed spring propeller

for naval locomotion, and a "winged cart" for land locomotion, which has been practically tried more than once during the present century.

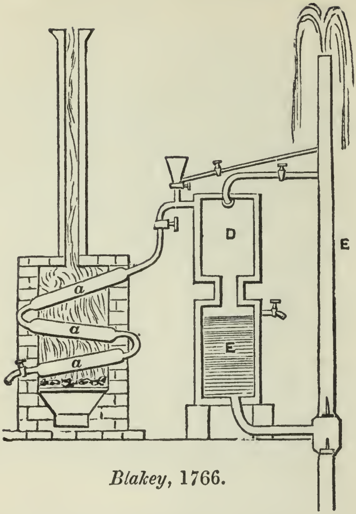
Dr. Black, 1762.—The properties of heat and steam were ably investigated by Dr. Black, who propounded the well-known doctrine of latent heat. A modern instance has been discussed of the extent to which the term "latent" is popularly used occured at the recent trial of the Midland Railway Company's servants, on account of a fatal accident. In answer to counsel, the Company's foreman stated his inability to speak positively to the condition of the piston, as it was "'latent' in the cylinder." On being asked what he meant by "latent," he replied, that if the learned counsel would place his papers inside his hat, on his head, he should say the papers were "latent" in the hat. In this sense the heat in steam may be called "latent," although known to be there in a diffused state.

Blakey, 1766.—Blakey introduced tubular boilers, containing the water in the small tubes, *a a a*, Fig. No. 84, round which the flame and hot gases passed to the chimney.

To keep the steam cylinder hot, he added an upper one, D, and employed air or oil as a piston between the water in E and steam in D. The rise and fall of the water in E he ingeniously arranged to open and shut the necessary cocks. The action was by admitting steam into D, which by its pressure on the aerial or oily piston forced the water out of E up the pipe F, and E was filled again from the well, as in Savary's engine.

This tubular idea of boilers has been successfully carried out, sometimes with the water surrounding the tubes as in locomotive boilers, or by having the water in the tubes as in Woolfe's, Gurney's, or Alban's boilers.

Fig. No. 84.



Blakey, 1766.

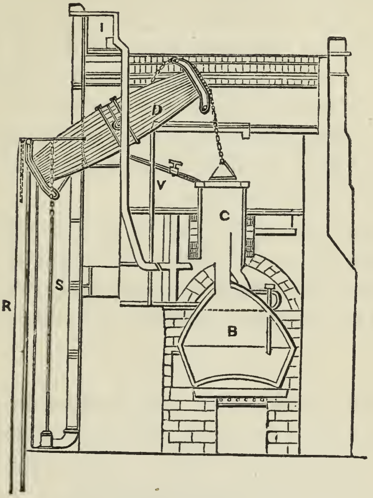
Smeaton, 1765.—The careful experiments made by this celebrated engineer reduced the performances of the steam-engine to the weight and measure suggested by Morland.

His experimental engine of one-horse power evaporated 6¼ lbs. of water by 1 lb. of coals, and required nearly 11 times more water for condensing than for generating the steam. It produced the greatest effect with a pressure of about 8 lbs. above the atmosphere. He also determined the relative steaming value of different coals, as given in p. 98, Vol. I.

This information enabled him to improve the various details of the atmospheric engine and its boiler, which he adapted for portable as well as for fixed duty. One of them, erected at Long Benton (Northumberland) in 1772, realized a duty of lifting 112,500 lbs. of water one foot high by 1 lb. of coals.

In 1775 he erected a very large one at Chacewater, having a

FIG. No. 85.



Smeaton, 1775.

cylinder of 6 feet diameter and $10\frac{1}{2}$ feet stroke. The beam D was made of twenty pieces of timber strongly bolted together. The cylinder C was firmly fixed to the side beams 1, 2, as well as on its end supports on the boiler B. The mine pump was attached to the rod R, and another pump S raised water to the cistern I, from condensation by injection into the cylinder. The rod V worked the steam and injection-valves.

The action of the engine was the same as in Newcomen's, air being the principal motive power.

In some of his boilers Smeaton inclosed the fire, and supplied the fuel by a feeding-tube, with the then good results of 7·88 lbs. of water evaporated by 1lb. of coals.

Cugnot, 1763—1771.—In 1763 this French engineer made a model of a steam locomotive, and in 1770 the French government had one constructed at the Paris arsenal, tried in 1771, and then *laid aside*. Through the favour of Monsieur Morin, Director-General of the Conservatoire of Arts and Machinery in Paris, illustrations of this first piston locomotive engine practically tried will be given in the next chapter.

The piston rods worked downwards, as afterwards adopted in Cornwall by Bull, to evade Watt's patent, and now in pendulous engines by various makers.

The inventor became reduced to poverty, and had a small pension from government; but the revolution stopped this, and a humane lady of Brussels relieved him until Napoleon granted him a larger pension than he had lost, but still only about 42*l*. yearly.

Watt, 1762—1800.—This very distinguished mechanical engineer was born at Greenock, in 1730, and died at his residence near Birmingham in 1819, after a long life spent in adding immensely to his country's resources. At Glasgow he became early acquainted with Dr. Robison, who, in 1759, suggested to Watt the application of steam to propel wheeled carriages. Like the earlier idea of Sir Isaac Newton, that steam could be made to produce locomotion, this suggestion was not practically followed up. The value of Britain's mineral produce rendered the application of steam to clear mines of water a more immediately interesting subject, to which Watt directed all his energies, with a success which astonished the world; the leading defect of Newcomen's engine, as improved by Smeaton, was the loss of heat arising from condensing the steam in the working cylinder. By careful experiments it was found that this loss amounted to about 32 per cent.; the steam being condensed in reheating the cylinder each stroke, besides the loss of time in doing so. In this state Watt found the steam-engine, and by

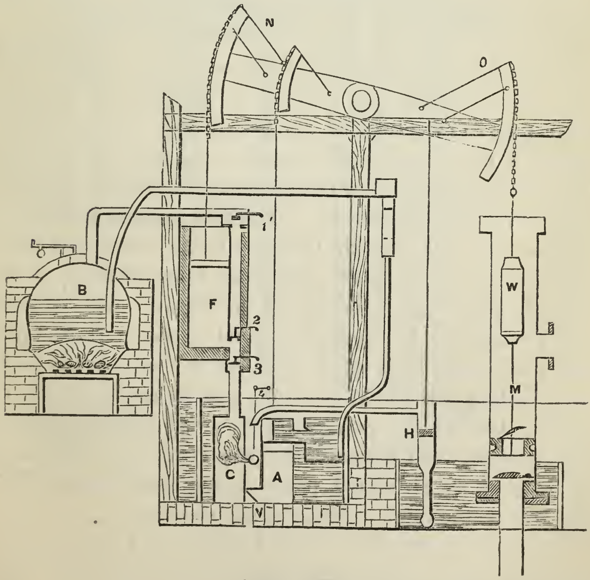
his vast improvements stamped his name upon it as if it had been his own original invention.

On models of Papin's high-pressure and Newcomen's low-pressure engines he tried several experiments, which from apprehension of danger from high-pressure steam, determined him in favour of low-pressure engines.

This opinion still largely but unfairly influences society, as is evident by the success of high-pressure locomotives on railways working with steam from 80 lbs. to 130 lbs. pressure per square inch.

After several trials on condensing the steam in another vessel connected with the cylinder, in 1769 Watt patented the addition of a separate condenser, C, Fig. No. 86, to Newcomen's engine. The condensed steam, injected water and

Fig. No. 86.



Watt, 1769.

air were withdrawn from the condenser C, through a foot valve, by the air-pump A, to the hot well, from which a feed pump supplied the boiler B. The pump H supplied the condensing water to the cistern, in which the air-pump and condenser are fixed. The conical steam-valve 1, the equilibrium passage-valve 2, the condenser passage-valve 3, and the injection-cock 4, were all opened and shut by suitable levers worked by the air-pump rod. To maintain the temperature of the cylinder equal to that of the steam, Watt closed its top with a cover, having a central stuffing-box through which the piston rod worked steam-tight. He also surrounded it with a "jacket" of wood or other non-conducting material, having steam between the jacket and cylinder. The air being thus excluded from the cylinder, the steam had to perform the duty done by the air in Newcomen's engine. The steam, therefore, entered by the top valve 1, to press down the piston and raise the water from the mine by the pump M, and to the boiler and injection-cistern by their pumps. The equilibrium passage-valve 2 was then opened, that the steam might pass to both sides of the piston, and the counterpoise weight W raise it and the air-piston to the tops of their respective cylinders again. The equilibrium passage-valve 2 was then shut, and the steam-valve 1, condenser passage-valve 3, and injection-cock all opened, that the steam below the piston might pass to the condenser, and steam from the boiler to force down the piston again, as seen in the figure. The air-pump kept a vacuum in the condenser equal to about 12 lbs. pressure per square inch, which with rapid condensation and a hot cylinder saved the 32 per cent. lost by condensing in the cylinder, besides the gain in time—a very important step in advance of previous engines. Still this engine was only single-acting, that is, giving out power during the downward, but none during the upward stroke of the piston.

Watt also proposed a rotatory engine, by having a piston working round a circular channel connected with the boiler

and condenser, with valves which were opened and shut by the steam and piston; but the valves were found to fail, and the piston to be injured in passing over the ports. Another plan was, by causing the steam to raise water through valves, as in Amonton's hot-air rotatory, but it was found to give out only a limited power. The double-acting cylinder was then invented, as supplying much of what was sought for by the rotatory class of engines.

Fig. No. 87.

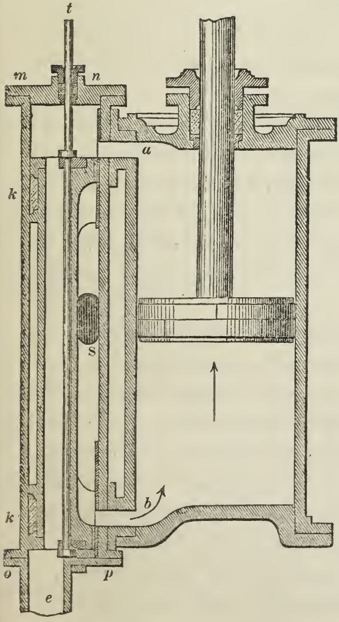


Fig. No. 88.

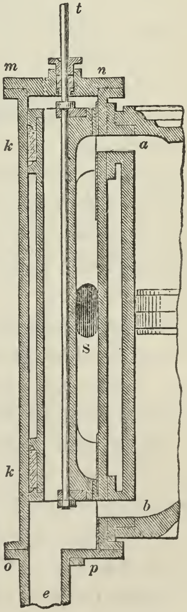


Fig. No. 89.

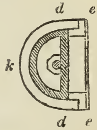
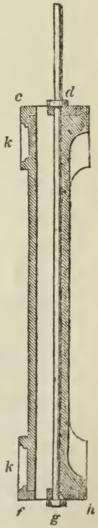


Fig. No. 90.



Watt's Double-Acting Cylinders, 1782, *and Murdock's Slide Valves*, 1799.

By making the equilibrium-passage a steam-pipe or chest to admit steam alternately above and below the piston, with equal facility of escape to the condenser, in 1782 Watt made the steam both raise and force down the piston, thereby giving out power in both directions. This judicious improvement constitutes the double-acting engine. Fig. 87 is a sectional view of a double-acting cylinder, having the steam entering at S and passing by *b* below the piston, and the condenser passage *a e* open to the top of the piston.

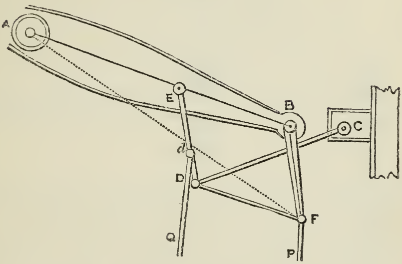
In Fig. No. 88 the steam-passage is open by *a* to the upper side of the piston, and the condenser-passage by *b* from below the piston. The conical valves, as in Fig. No. 86, worked from the beam, opened and closed the steam-passages until Murdock, one of Watt's able assistants, introduced the eccentric motion and long D slide-valve in 1799.

Figs. 89 and 90 are sections of the long D slide-valve. The flat faces *h i* slide over the cylinder steam-passages *a b*, alternately opening them to the cylinder, and from the cylinder to the condenser. The convex stuffed faces *k k* press slightly against the steam-chest cover to keep the faces *h i* steam-tight over the passages or "ports" (as they are called) leading to the cylinder.

Whilst the single-acting force was downward, a chain conveniently connected the piston rod to the beam, but as a flexible chain could not communicate upward motion, Watt tried a racked piston-rod worked by a toothed sector on the beam end. This proving noisy, and being easily deranged, in 1784 he patented the beautiful arrangement of levers, called the parallel motion, whereby to connect the vertical motion of the piston-rod to the circular motion of the end of the beam. By making A E and C D, Fig. No. 91, of equal lengths, but moving in opposite fixed centres, A C, the convexity of their equal curves would be opposite each other, when the centres A C were in the same plane.

On connecting them together by the link E D, its centre would move nearly in a right line. Another nearly vertical

FIG. No. 91.



Watt's Parallel Motion.

point is obtained by making B F equal to E D, and D F to B D. The centres of E D and B F would then move parallel to each other, but as B is a greater distance from the centre of motion, A, than E is, it would move through a greater height.

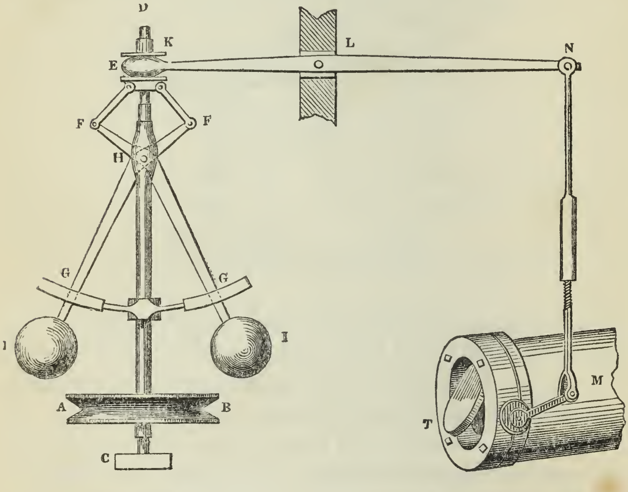
In practice, the radius rod centre, C, is fixed near the line of the piston-rod, and the length of B F below the plane of A, that the links may be arranged to make F *d* the neutral points of the opposite curves.

The piston-rod is usually attached to the point F, and the air-pump rod to the point *d*, but the points may be varied according to the stroke required.

Parallel motions for beam engines, more geometrically accurate but also more complex than Watt's, have been proposed and some of them tried, but failed to compete with it for simplicity and durability. To guard against irregular generation of steam affecting the motion of the engine, Watt introduced the throttle valve, worked by the governor previously employed in corn mills to regulate the velocity of the stones.

In Fig. No. 92 the vertical shaft D is connected directly by the pulley A B to the fly-wheel shaft, that their velocities may be proportional to each other. The balls I I are jointed to D at H, and by the short levers F F to the sliding socket

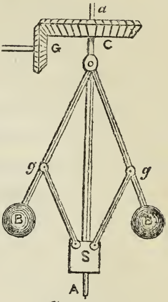
Fig. No. 92.



Governor. *Throttle Valve.*

H. The lever E N moves on its centre L, and connects the sliding-socket H to the throttle-valve T in the steam pipe M. When the velocity of the engine increases, the balls recede from each other in the guides G G as they accumulate centrifugal power, and draw down the socket H, which by the lever E partially closes the valve, as in the figure, and checks the flow of steam to the cylinder. When the velocity of the engine decreases, the balls approach each other and raise K as they give out their acquired power, which opens the throttle-valve for a free admission of steam to the cylinder.

Fig. No. 93.



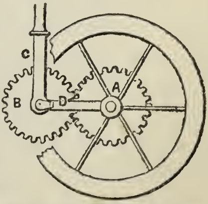
Governor.

Another form is by connecting the balls to the upper part of the vertical shaft, A *a*, Fig. No. 93, with the sliding-socket, S, below. Single links, *g g*, then connect S with the balls, and bevel gear, C G, either at the top or below, connect the governor with the fly-wheel. The action of the governor is both delicate and good.

Combined with Fitzgerald's fly-wheel, these admirable inventions made the steam-engine so regular in its movements, that it became very desirable to apply it to give motion to machinery. Papin, Hulls, Masborough, Watt, and others, had all given more or less attention to convert its reciprocation into rotation, with no better result than the ratchet rotation, when James Pickard solved the problem in 1780 by applying the crank and connecting-rod to the steam-engine. He afterwards entered into partnership with Wasborough of Bristol, and several engines were erected under Pickard's patent.

Watt, however, complained that the crank was a part of his design, unfairly obtained through one of his workmen, but rather than cause litigation he invented and used the sun and planet rotatory motion during the existence of Pickard's patent, which rendered it of comparatively little value to the patentee, although a valuable arrangement.

Fig. No. 94.



Sun and Planet Motion.

The peculiar action of the sun and planet motion is deserving of notice. The sun wheel A, Fig. No. 94, is fixed on the fly-wheel shaft, and the planet wheel B is attached to the connecting rod C leading to the beam. A separate link, D, connects the wheels A B of equal diameter and teeth together, that they

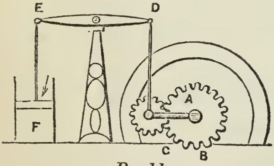
may be in gear at all parts of their revolution. Planet-like, the wheel B revolves round the central wheel A, and as the centre of B's circuit is the periphery or circumference of A, the ratio of the diameters of their respective circles of revolution is as 2 to 1. Hence the sun wheel revolves twice round its own axis whilst the planet wheel revolves once round the sun wheel.

This is an advantage not possessed by the crank for working with a slow motion of the piston and light fly-wheel. The crank is, however, more simple and durable, which has led to its general adoption for converting reciprocating into rotatory motion.

After the first successful application of steam-engines to machinery, more graceful forms and superior finish were given to the various parts by Watt, until the steam-engine became a beautiful as well as a useful machine.

Little alteration either in the action or details of condensing beam-engines has taken place since Watt's time. It may however be remarked, that one of his best engines applied to Mr. Lacy's flour-mill, at Birmingham, was found to produce more coarse flour in grinding wheat than was done by water power. This irregularity of motion was cleverly remedied by Mr. Buckle, one of Watt's pupils, and now of the Mint, London. To the fly-wheel shaft, A, by means of the toothed wheels, B C, and lever D E, he connected an atmospheric cylinder, F. The wheel B had twice the number of teeth in C, that their revolutions might be made in equal times. When the velocity of the engine tended to increase, it had to raise the piston, P, against the air, but when the velocity tended to decrease, the pressing the air on P gave out power to B. This greatly improved the regular action of the engine, and secured the desired end of increasing the proportion of fine flour.

Fig. No. 95.



Buckle.

Small engines dispense with the beam and use fixed guides

for the parallel motion. They are variously arranged according to taste or the duty required, but are all double-acting and alike as regards the action of the steam. Boilers have varied and still vary considerably. Newcomen and Smeaton employed a circular form with a convex top like a hay-cock, but Watt adopted a form resembling a covered waggon, from which it took its name. By improved flue and other arrangements the evaporation was increased to 8·6 lbs. of water by 1 lb. of coals, or 9·4 per cent. more than Smeaton's.*

Fig. No. 96 is a transverse, and Fig. No. 97 a longitudinal section of a waggon boiler, with its modern self-acting feeding apparatus. One mode of feeding a high-pressure boiler without a pump has been explained by Fig. No. 79, and the plan of feeding a low-pressure boiler by its own action without a pump now claims our attention. The principle is by a column of water equal in weight to balance the pressure of the steam in the boiler. As has been shown, a column of water 34 feet high has a pressure of $14\frac{3}{4}$ lbs. per square inch, which gives 2·3 feet high for each 1 lb. of pressure in the boiler above the atmosphere, or 23 feet for 10 lbs. pressure, besides the allowance necessary in practice. At the top of this columnal pipe *l*, and between it and the water cistern, a valve *k* is fitted, and kept in its seat by the weight *w*, whilst the other end of the lever *v* is connected to the stone float *m* in the boiler.

* It may be mentioned here, that in 1782, Mr. Achard, and in 1790, M. Bettancourt, investigated the comparative properties of the vapours from water, and from alcohol.

In 1790, M. Pronig wrote on the steam-engine, on the force of steam of different temperatures, and on combustion.

In 1793, Mr. Curr had an engine constructed on Savary's plan, which raised 120,000 lbs. of water one foot high by 1 lb. of coals, or about one-half of what Watt's engine did.

In 1795, Mr. Banks wrote on the useful effect of atmospheric engines; and in 1803, on the strength of the parts of engines.

In 1797, Mr. Curr gave the proportions for a 61-inch cylinder engine, capable of lifting 130,000 lbs. one foot high, by 1 lb. of coals; and in 1801, Mr. Dalton published tables of the force of steam of different temperatures, which with Mr. Southeron's steam tables, have only recently been superseded by those of M. Regnault, of France.

FIG. No. 96.

Waggon Boiler—Transverse Section.

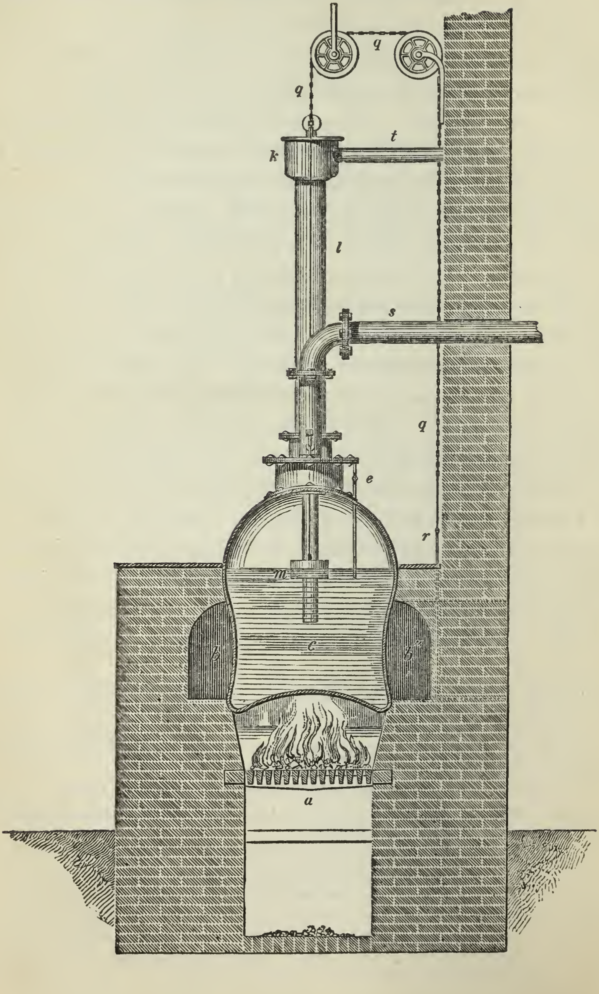
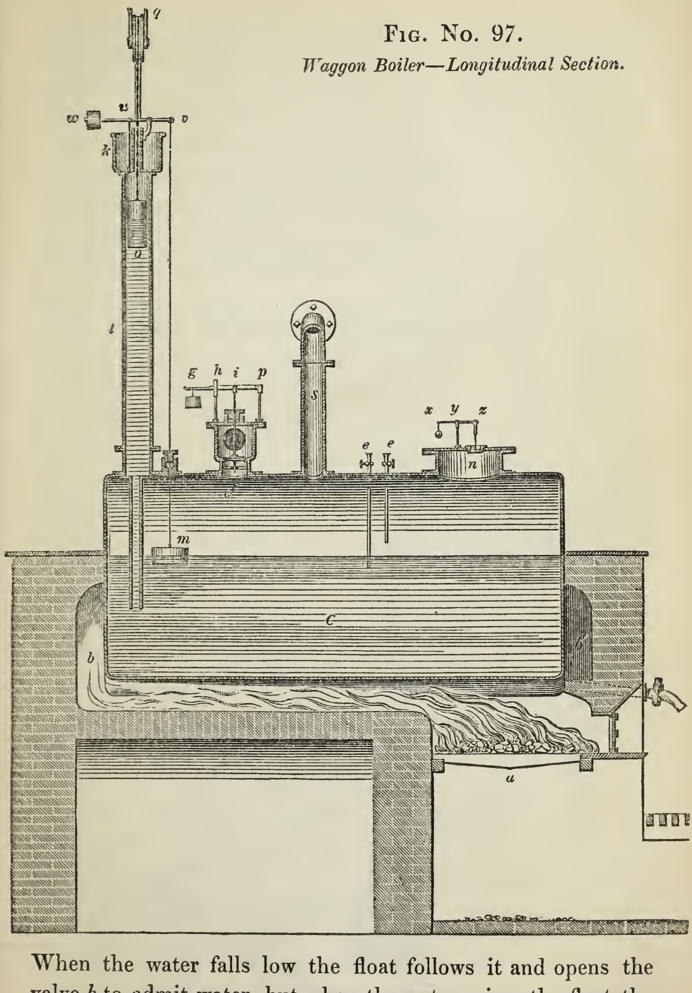


FIG. No. 97.
Waggon Boiler—Longitudinal Section.

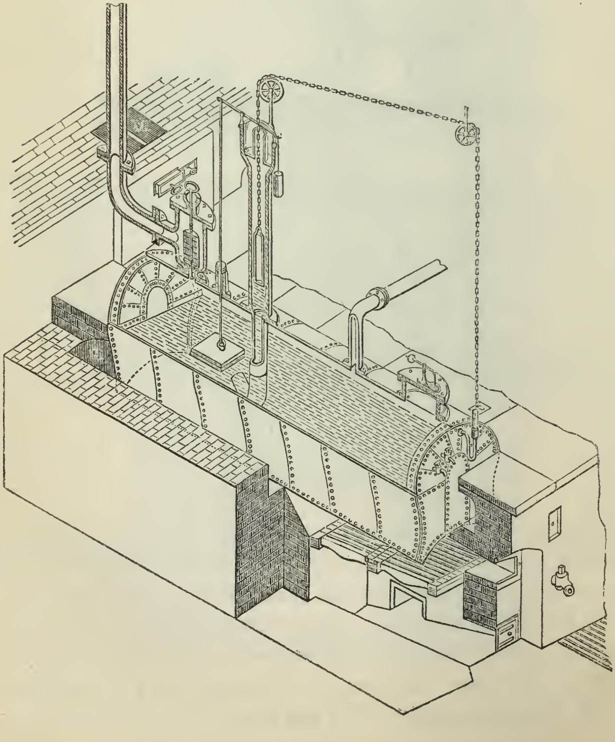


When the water falls low the float follows it and opens the valve *k* to admit water, but when the water raises the float the tension on *v* is relieved, and the valve *k* is closed by *w* to exclude the water. The water in the boiler is thus made to regulate its own supply. The flue dampers is also ingeniously

worked by the float *o*, in the column of water in *l*, passing by a line over the pulleys *q q* to the damper. The height of the water in *l* depending upon the pressure in the boiler, when that pressure increases and raises the water the damper falls and partially shuts the flue to check the draught on the fire; but if the steam pressure decrease, the water falls and the damper is raised to increase the draught and combustion. Two steelyard safety valves *g*, *h*, *i*, *p*, and *x*, *y*, *z*, regulate the pressure in the boiler. *e*, *e*, the gauge-cocks. S. the steam-pipe leading to the engine.

Fig. No. 98 is a perspective view of the complete self-

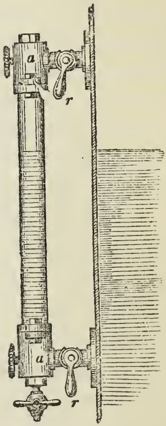
Fig. No. 98.



acting waggon boiler, partly in section to show the water, fire-grate, and construction. To the left is shown a mercurial syphon gauge, and a glass gauge is also now usually placed in front to show by sight the height of the water in the boiler.

Fig. No. 99 is a glass gauge employed both on locomotive and stationary boilers, that the height of the water may be seen. *a a*, two stuffing-sockets, into which the glass tube is fitted steam-tight. It is connected to the front of the boiler by the cocks *r r*, and the cock *s* is for blowing through the tube or clearing it. The lower cock admits the water, and the upper one the steam, that their relative position may be the same in the tube as in the boiler. The water should always be some height in the glass tube, and at a recent fatal accident at Bristol the witnesses remarked that the boiler was out of gauge, signifying that the water could not be seen in the glass. This is a dangerous state, requiring careful but instant precaution to be taken to prevent an accident.

FIG. No. 99.



In 1776 Watt introduced the expansive action of steam cut off from the boiler, at Soho and other places. He calculated that when cut off at half-stroke the performance would be as 1·7, at one-quarter stroke as 2·4, and at one-seventh stroke as 3 in economy as compared with admitting steam during the whole length of the stroke. In 1778 one of them was erected at Shadwell water-works, and in 1781 Hornblower patented the same principle, but expanded the steam in a second cylinder, which led Watt to patent his single-cylinder plan of expansion in 1782. The advantages and comparative merits of these plans have been illustrated under the head of the expansive force of steam, showing the practical result in favour of Hornblower, although the absolute power given out is in favour of Watt's single-cylinder plan.

A locomotive engine and a steam indicator were also amongst Watt's inventions, and will be described under their respective heads. The indicator is said to have been suggested by his assistant, Mr. Douglas.

We have pointed out that the generation of steam and its economical employment were two distinct processes, each requiring to be duly attended to. This is very clearly shown in Watt's success, and also in the more recent corresponding success over Watt's engines. His first double-acting engine, erected at Albion-mills, London, realized a duty equal to raising 229,971 lbs. 1 foot high, or rather more than double Smeaton's Long Benton engine. Yet there was barely 10 per cent. of this gained by Watt's boiler, leaving 90 per cent. due to the more economical application of the steam after it was generated.

With such able rivals as Smeaton, Hornblower, Trevithick, Bramah, Wasborough, and others, often disputing the validity of his patents, or seeking to evade them, Watt's ultimate success has imperishably associated him with the steam-engine.

It should not however be forgotten, that but for the business habits and ample fortune of Boulton, his partner Watt could not have maintained a struggle which involved an expenditure of about 78,000*l.* to defend his patent rights and introduce his engines before any profit was realized. This enormous expenditure led to a renewal of his patents by the Privy Council.

For an elaborate description and engravings of Watt's improved engine and modern examples, see the 3rd edition of Tredgold on the Steam Engine.

1774—1800.—During the time that Watt was carrying out his steam-engine improvements other engineers were also engaged in the same field, both in France, in America, and in Great Britain, some of which will be noticed.

In 1774, Compte Auxeim and Perrier, of France, constructed and tried a paddle-wheel steam-boat, but did not persevere with it. In 1776, Bushnell, of America, proposed a screw

propeller for ships, which gave them a backward or forward motion, by reversing the revolution of the screw.

In 1776, Wasborough, of Bristol, a rival of Watt, proposed to propel ships, raise water, or drive mills, by steam-engines with a ratchet-wheel rotation.

This enterprising engineer erected several of this class of high-pressure engines, and in 1781 was desired to fit one up at Deptford for the government, where soon after Watt appeared as a competitor, and Smeaton as a consulting engineer. On the ground that no reciprocating lever could produce "perfect circular" motion, Smeaton recommended that a water wheel should drive the machinery, and a steam-engine raise the water to drive the wheel.

In 1781, a steam-boat 140 feet long was successfully worked on the Soane in France by the Marquis De Jeuffrey.

Hornblower, 1781.—The introduction of Watt's pumping engines into Cornwall, accompanied by Murdock, excited much local emulation to compete with or excel them, which has led to the great economy of modern Cornish engines. Amongst those local engineers, Hornblower, during Watt's patents, and Trevithick, principally after their expiring, most distinguished themselves.

In 1781, Hornblower patented a judicious arrangement of an additional cylinder, wherein to employ the expansive force of steam after it had done its duty in a smaller cylinder, on the plan of two cylinders, first suggested by Dr. Falcke, for the expansive action of steam.

For a section of the cylinders as improved by Woolfe, and their comparative value to a single-cylinder engine, see Fig. 51, page 208.

The principle of expansion, the condenser, cylinder-passages, and details were all so similar to Watt's single-acting engine, that after a law-suit he obtained payment for the use

of his patents in Hornblower's engines, which were also only of the single-acting class.

The beam, mine-pump, counterpoise-weight, and chain connection being similar to Watt's, need not be further described.

Besides Hornblower, various engineers attempted to construct efficient engines without infringing Watt's patents, but they nearly all failed to do so with low-pressure steam without a separate condenser.

Hornblower's rotatory engine had two moveable pistons alternately moving round the steam cylinder, and acting as abutment valves to each other. A tappet valve in each piston was opened as it came in contact with the abutment one, which was then also set at liberty, and the other arrested by sliding levers behind it, and so on alternately.

Bramah, 1783—1797.—Bramah, another rival of Watt, proposed to propel ships either by paddle-wheels or by a screw, on the principle of the smoke-jack vanes. He also improved the construction of the two-way cock of Papin, by making it turn quite round, to equalise the wear.

His letter of 1797 to Sir J. Eyre, Chief Justice of the Common Pleas, strongly urging the demolition of Watt's patent, is one amongst many instances of one engineer seeking by casuistical pleading to injure another from interested motives.

Bramah's chief objections were, that Watt's engine was much more complete than the specification in details, more particularly in, 1st, the cylinder top being closed; 2nd, ingenious piston and valve-rod stuffing-boxes in the covers; 3rd, gun-metal valves curiously worked; 4th, stoppage of the engine by any one defect; 5th, construction of stuffing-boxes; 6th, cylinder bottom closed, and steam acting above and below the piston; 7th, the "cuning" condenser, valves, and pumps. He concluded by declaring his inability to make an engine by the specification, and that the patent was thus invalid, but he failed in the attempt to convince the Court.

Bramah also proposed three varieties of a rotatory engine, by a piston moving round a steam chamber divided into two parts, alternately opened to the boiler and to the condenser by slide valves working at right angles to the piston, and alternately pressed against it by an eccentric motion. He is, however, now chiefly distinguished by his valuable hydraulic press and celebrated lock, requiring so much skill to pick, at the Exhibition, by that clever artist, Mr. Hobbs.

Fitch, 1783—1788.—In 1783, Fitch, an American, proposed a steam-boat with six oar-propellers on each side, and so arranged that each opposite three should work simultaneously, and enter the water as the other six were leaving it. Motion was given to the oars by a steam-engine with twelve-inch horizontal cylinder and three-feet stroke, working a wheel eighteen inches in diameter, suitably connected to the oars. In 1783, he moved a boat by paddles on the Delaware: and on trial at Philadelphia, in 1789, a speed of eight miles an hour was obtained; but Fitch's supporters having left him, he fell into poverty, and in despair drowned himself.

Rumsey, 1784—1793.—Rumsey's American steam-boat was propelled either by poles in shallow water, as on Hull's plan, or by pumping water in and out of a pipe along the bottom of the vessel. The pump was two feet diameter; and during the upward stroke the water entered by a valve, which was shut by the returning stroke, and the water expelled at an orifice about six inches square in the stern of the vessel. In 1793 a speed of four miles an hour was realized on the Thames, against the wind and tide, by one of Rumsey's boats.

Oliver Evans, 1784—1804.—While Watt was devoting his talents to the steam-engine in Great Britain, a kindred spirit in America, Oliver Evans, was devoting all his energies also to extend its usefulness in the New World. Watt preferred low-

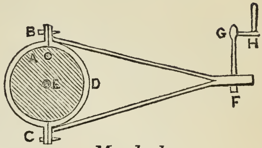
pressure steam; Evans, high-pressure steam; and ever since both nations have generally followed the guidance of these leading men. The low-pressure engine is most complex, requiring an air-pump condenser and injection-pump, more than is required by a high-pressure engine, where the steam escapes into the air, as daily seen from locomotives.

Strongly impressed with the locomotive capabilities of high-pressure steam-engines to move ships or waggons, in vain Evans sought to obtain pecuniary means to test his ideas. His locomotive opinions were derided as emanating from insanity, consequently he found no Boulton to aid genius struggling against poverty and prejudice in those fields of steam enterprise now so prominent throughout the world. He introduced the superior cylindrical boiler with an internal flue, and leading back below the boiler to the chimney. To further economise fuel, the exhausting steam was made to pass spirally through a pipe in a cistern of water to heat it for the boiler, as also done by Trevithick afterwards.

In 1804, he showed the capability of his engine for both land and river locomotion, by temporarily fitting one of them on a rough waggon, and afterwards in a boat.

Murdock, 1784—1789.—This able assistant of Watt survived him about twenty years, leaving a name intimately associated with Watt's steam-engine in Cornwall, where he was much respected. The eccentric motion and long D slide-valve were his invention, and as a modification of this plan is employed in locomotives, its action will be explained. The hole A in the circular sheave B C D is at some distance from its centre E, which gives it an eccentric motion round the crank shaft A, on which it is fixed. Since A is the centre of motion and E the centre of the sheave, the distance between them is equal in effect to a crank. If that distance is two and a half inches on each side of A during each revolution, the point F of the eccentric strap and rod, B C, D F (fitted so as to move

Fig. No. 100.



Murdock.

easily round the sheave E), would move five inches, thus converting rotatory into rectilinear motion.

For vertical cylinders the levers G, H, fixed on the centre N, connect the eccentric rod with the slide-valve rod *t*, Fig. No. 100. For horizontal cylinders, the connection may be direct, or by intermediate mechanism, as will be shown.

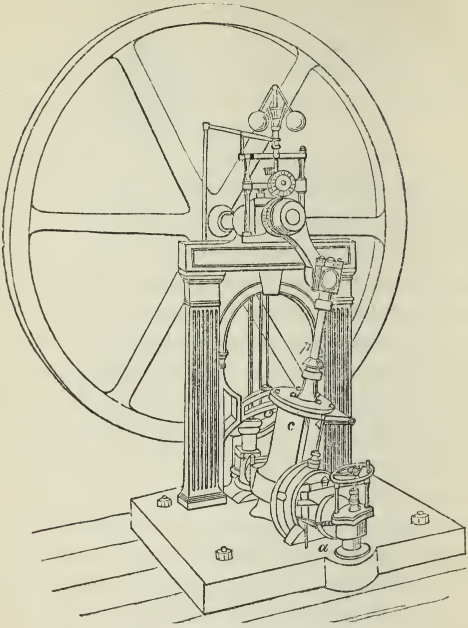
Murdock's rotatory engine consisted of two toothed wheels working in a steam-tight casing, and gearing into each other. The steam enters directly against the teeth then in gear, and forcing them round passes out at the other side to a condenser.

The cylindrical slide-valve, the cylinder boring-bar, and iron cement* for steam-pipe joints, were a few of his contributions to the steam-engine.

He also introduced gas, and the brilliant gas illumination of the Soho works at the Peace of Amiens attracted universal attention, which has led to its present extended and still extending use. A model of an oscillating engine, and also a model of a locomotive engine, both made by Murdock in 1785, were exhibited in the Industrial Palace as the earliest working models of these engines in this country. The locomotive model will be described in the next chapter. The object of the oscillating cylinder C, Fig. 101, is to keep the piston in a line with the angularity of the crank, without a parallel motion or separate connecting-rod. For this purpose the cylinder is suspended on two hollow centres, which serve as steam ports. When the crank is at its greatest angle the cylinder takes the

* This cement was made of sixteen parts cast-iron filings, two parts of muriate of ammonia, and one part of sulphur, mixed together and kept dry till required, when it was made into a paste with water, and calked into the joint. The oxydation cemented the mass into a solid which answers well for such joints.

FIG. No. 101.

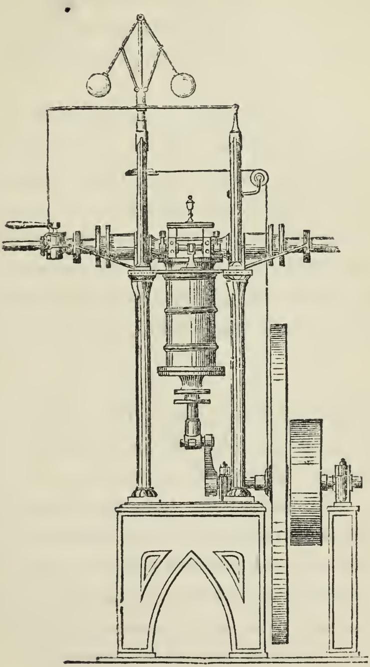


Penn's Oscillating Engine.

same angle, and in like manner at the opposite extreme, or any other part of the revolution. On this principle very compact and good engines are constructed by Messrs. Penn, of Greenwich, one of which is shown, Fig. 101; and also by Napier, of Glasgow, and others.

Messrs. Joyce, of Greenwich, have recently constructed a double-cylinder pendulous oscillating engine of forty-horse power, which is said to be an economical one. The pendulous engine is so called from its cylinder being suspended from its top end on centres like a pendulum, with the piston-rod working out below, as was introduced by Bull in 1790, to evade Watt's patent, although previously used by Cugnot.

FIG. No. 102.



Joyce's Pendulous Engine.

Fig. 102 is a front view of one of Joyce's single-cylinder pendulous engines, showing its simplicity of arrangement and mode of action.

In 1784 M. R. Cameron proposed a rotatory engine, either by a piston moving in a circular channel, or by a piston moving in a lateral path in the cylinder, so that its rod had a screw-like motion forwards as it turned round. He also proposed a long cylinder, divided into two by a transverse central

partition, through which the piston-rod worked, and a separate piston in each half. The upper piston was acted on by the atmosphere, and, the lower one by the steam, which was condensed below the piston, and, drawn off by the upper piston in its ascent, caused by a fresh supply of steam.

W. Cook, 1787.—By jointing a series of flaps or pistons of thirty-six square inches area to the circumference of a wheel half inclosed in a steam-tight case, Cook calculated he would have a constant acting force of 531 lbs. on these pistons. The mechanism was so arranged that each piston was closed in a recess in the wheel, as it entered the steam-case, and, opening by its gravity, the steam impelled it onwards, while the casing again closed it to admit its rotation, and so on with each flap or piston.

Patrick Miller, 1787—1796.—This enterprising Scottish gentleman spent about 30,000*l.* in seeking to improve the naval and artillery defences of the nation, yet, like many poor inventors, he was neglected. An equal party expenditure would probably have commanded the attention of the government, for patriotism and political power are two different subjects in most countries. So true is the poet's remark, that—

> " Truths would you teach to save a sinking land,
> All fear, none aid you, and few understand."

The carronade was Mr. Miller's invention ; and in naval efforts he constructed some twin and treble-keeled paddle-boats. With two keels, the paddle-wheel worked between the keels ; and with three keels, one paddle-wheel on each side of the central keel. The keels were made to work simultaneously by one steersman. With a double-keeled boat a speed of four miles an hour was obtained in the Frith of Forth, by five men working the paddles by a capstan. The boat was sixty feet long and fifteen feet wide.

In these experiments he was actively seconded by his chil-

dren's tutor, Mr. Taylor, who successfully urged him to employ a steam-engine to turn the paddle-wheels. In 1788 the first trial was made on Dalswinton Lake, in a double pleasure-boat worked by one of Symington's ratchet-motion engines with a four-inch cylinder. With this very small engine a speed of five miles an hour was obtained, which led to a double engine of the same class, with eighteen-inch cylinders, being applied to a boat on the Frith and Clyde Canal in 1789-90, and a speed of seven miles an hour realized. Whether the cost of these trials had exhausted Mr. Miller's resources, and a gentlemanly delicacy prevented his soliciting aid, or other causes operated to induce him to give up his steam-boat experiments when they had thus proved successful, is not known; but from this time he turned his attention principally to agricultural affairs. Mr. Taylor received a pension of 50*l.* per annum from Lord Liverpool; and in 1837 each of his four daughters received 50*l.* as a gift from Lord Melbourne's government, for his aid in introducing steam-boats.

Earl Stanhope, 1790.—As a practitioner in science and art this nobleman holds a high position, regarding it as more honourable to gain an independence as a mechanic than live upon the bounty of friends or on the public purse.

In 1795 he tried a steam-boat moved by paddles, which opened to act against the water, but closed to be drawn through it, like a duck's foot, and with a flat-bottomed boat attained a speed of three miles an hour. R. Fulton, the American steam-boat engineer, showed his lordship drawings of a steam-boat in 1793-4, and it is said urged the advantage of paddle-wheels over the duck-foot oars, but without effect.

François' engine for draining a morass had the water entering the cylinder through a bottom valve by atmospheric pressure, to be expelled by steam from the boiler without any piston. The water to be raised first entered a bucket balanced on a pivot, but with unequally long ends, so that as it filled

the long end preponderated and emptied out the water, when it resumed its balanced position again. The alternating motion of the tumbling-bucket was made to open and shut the steam and eduction cocks, somewhat after the plan of Gensanne.

Keupel proposed a rotatory engine by jointing a horizontal tube centrally on the steam pipe, and producing rotation by the emission of steam from small orifices at opposite sides of the tubular arms, as in Hero's ælopile.

Sadler, 1792.—Sadler proposed rotation by steam issuing from similar arms to Keupel's, at great velocity within a case, and renewing the motion by condensing the steam internally, so that the air became the motive power. His reciprocating engine had no beam or parallel motion, but had vertical guides for the piston and air-pump rods to work on by small wheels. The air-pump rod was extended to give motion to a lever pressing the valves and cocks. Although inferior to Watt's, yet, in a competition, the naval authorities preferred Sadler's engine to that of Watt's at that time.

Nuncarrow proposed an ingenious plan of applying a condenser to Savary's engine, for raising water to turn a wheel and drive machinery from this water wheel.

Fenton Murray and Wood, of Leeds, improved the details of the valves, air-pumps, and boilers, along with horizontal cylinders, where most convenient. They also fitted a throttle-valve in the chimney, worked by a small cylinder fitted on the boiler, which partially closed the chimney when the steam was high, but left it open when steam was low in the boiler.

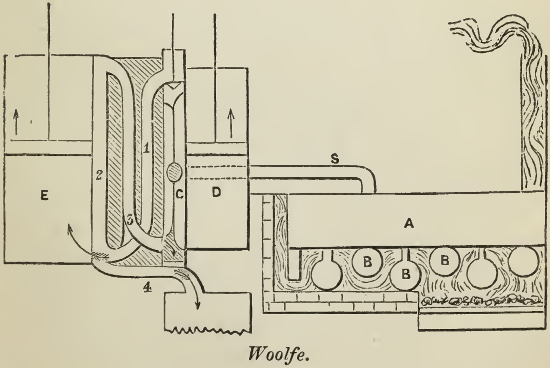
J. Robertson, of Glasgow, proposed a long cylinder with two pistons, that the steam, which usually escaped past the upper piston, might act on the second one, and erected some engines on this plan which worked satisfactorily, until a better class of pistons and cylinders rendered such a plan unnecessary.

At the expiry of Watt's patent, there were only about 1400 horse-power of his engines at work in London, Manchester,

and Leeds, so much had prejudice and interest done in retarding the general introduction of this valuable machine.

Woolfe, 1796—1804.—By making Hornblower's engine double-acting, like Watt's, and using higher pressed steam, generated in an improved tubular boiler, Woolfe produced a very efficient class of engines. The boiler A B, fig. No. 103, consisted of six, eight, or more metallic tubes, placed transversely across the fireplace and flues, and connected to a main steam receiving-pipe A, under which a partition wall divided the flue into two. The fire acted directly on the three first tubes, and the products of combustion passed alternately over one tube and below the next until they reached the back of the boiler, when they passed round the end of the partition, and continued their course alternately over and under the tubes until they reached the chimney at the fire end of the boiler. Two half-length steam receiving-pipes were over this part of the transverse pipes, and also connected with the main steam-chamber A, from whence the steam passed by the pipe S to the

FIG. No. 103.



Woolfe.

cylinder steam-chest C, from which the valve V admits it alternately above and below the piston in D, and also alternately

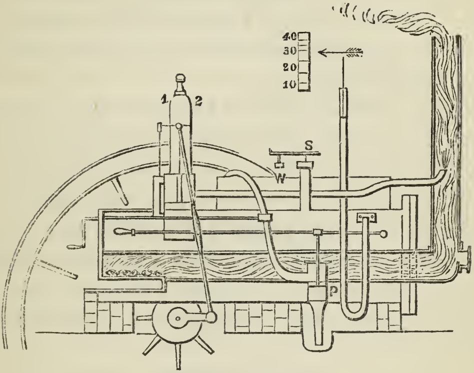
from the top of D to the bottom of E, or from the bottom of D to the top of E, by the double connecting passages 1 3. The condenser passage 2 4 communicates with both sides of the piston in E, that it may work in a vacuum. Both the pistons are thus simultaneously moved upwards or downwards at the same time. Sim's engine of this class has the two cylinders on the top of each other, like Cartwright's cylinder and air-pump; but M'Naught places the small cylinder at one end of the beam, and the larger one near the other end, that they may work at right angles to each other, like two separate engines. Both classes are favourable for efficacy and economy. In these varieties of Hornblower's engine, there is the uniform force of the small piston combined with the decreasing force of the large piston, which gives a more equal mean than is obtained from an equal expansion in one cylinder, although, as has been shown, the total force evolved is greatest for one cylinder.

Trevitheck, 1790—1816.—From 1790 to 1800 this able engineer, in connection with Bull, one of Watt's former workmen, erected several engines with double-acting cylinders on Watt's plan; but to evade his patent, Bull worked the piston-rod through the bottom instead of the top, which on a trial the judges held to be legal.

Trevitheck's acquaintance with Murdock and his models at Redruth led to his celebrated locomotive of 1803, combining the principal features of both models in one engine. Like Evans, Trevitheck preferred high-pressure steam, and his first patent engine had a spherical boiler set in a fire-brick case, with a heating flue all round. The cylinder was fitted into the boiler to maintain its temperature, and a two-way cock, worked by a double eccentric cam on the fly-wheel axle, admitted steam to and from the cylinder. Another plan was to suspend the case, boiler, and cylinder on centres, that the piston might adapt itself to the angularity of the crank; or to suspend the cylinder only, like Mur-

dock's. He afterwards adopted a cast iron boiler, nearly similar in form to Evans', as in Fig. No. 104, where the fire is placed in one end of the central flue, whilst the other end

FIG. No. 104.



Trevitheck, 1800.

terminates in the chimney. The cylinder is fitted into the boiler, and the fixed guides 1 2 keep the piston-rod in a line with the cylinder. A connecting-rod down each side communicates the piston motion to the cranks and fly-wheel. The exhaust-pipe passed through the cistern W to heat the water for the boiler—also similar to Evans' plan; but Trevitheck's terminated in the chimney, which ultimately led to that important part of a locomotive, the blast pipe. P the cold water pump, M the syphon mercurial gauge, S the steel-yard safety-valve. The boiler pump was on the opposite side.

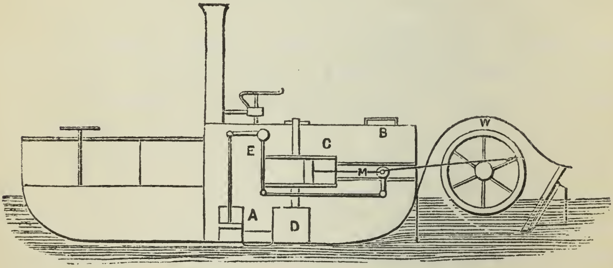
In 1802 Trevitheck patented a common road locomotive engine, which was successfully tried near London, and on a mineral railway in 1805; but having run off the road it lay in the ditch as if a worthless combination of mechanism. Like Evans', Trevitheck's success was greatest with fixed engines, and after the expiry of Watt's patents, in 1800, he introduced

high pressed steam, expanding to a low pressure, with so marked economy that the Court of Spain sent him out with regal honours to drain the silver mines of Peru. The locomotive, neglected by the public, was necessarily neglected by the inventor for the more inviting Spanish commission, which however also ended badly, and Trevitheck returned unrewarded to England, and continued to devote his talents to improve the steam-engine.

Symington, 1786—1804.—In 1786, Symington exhibited a model of a locomotive at Edinburgh, but I have not been able to get any particulars of its arrangement. He also tried to combine Newcomen's atmospheric plan with Watt's separate condenser, yet evade the patent, but failed to do so.

Symington's experience in Scotland with Messrs. Miller and Taylor resulted in his constructing the first paddle-wheel steamboat of the modern class. Supported at the time by Lord

FIG. No. 105.



Symington, 1802.

Dundas, it was called "Charlotte Dundas," after his lordship's daughter. Fig. No. 105 is a diagram of its machinery. The boiler B supplied steam to the horizontal double-acting cylinder C, whose piston-rod is kept parallel by the motion M, and connected by a rod and an outside crank to the paddle-wheel W, to produce rotation in the usual manner. The condenser D

and the air-pump A are worked by the cranked lever E, connected to the piston-rod motion. This is a simple and effective plan, which, excepting the condensing apparatus, has been adopted in modern locomotive engines. In 1802 this boat, with a twenty-two-inch cylinder and four-feet stroke, drew two loaded seventy-ton boats, against a strong breeze, at the rate of three and a half miles per hour; but the canal proprietors objected to its use, for fear of the waves injuring the banks. Symington's means were gone, and this efficient steam-boat was laid up in Scotland, near Brainsford, for years exposed to public view—a valuable combination, yet unable to find public support.

When reduced to poverty, and his friends appealed to the government on his behalf, Symington was presented with 100*l.* from the Privy Purse in 1825, and afterwards with 50*l.*!

Cartwright, 1797.—This reverend and talented gentleman patented an ingenious parallel motion, metallic piston, an air-pump, and external condenser. He also proposed a rotatory engine with three pistons and double admission and exit passages for the steam. Power looms, and carriages without horses, were also amongst his plans.

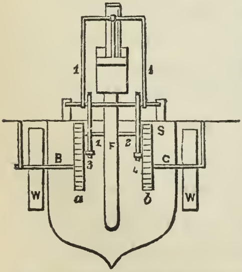
In his reciprocating engine he proposed to use alcoholic vapour, which external condensation did not affect, so that it could be used again and again. His parallel motion was by having two wheels of equal diameter connected to a cross head on the piston rod, and, as the cranks were always opposite to each other, their obliquity was balanced to work the piston-rod vertically. The air-pump was immediately below the cylinder, and both worked by one rod for both pistons.

Hall's patent tubular condenser, as applied to the "British Queen" and other steamers, is an improved form of Cartwright's plan of condensing by external cold. The metallic packing of modern pistons are modifications of Cartwright's piston. In this way the ideas of one inventor are adopted by others in new combinations of greater efficiency.

Fulton, 1793—1807.—This able and persevering man had been long engaged in promoting various plans of steam navigation, and other projects, before he saw the forsaken steam-boat on the Clyde canal. Having visited Scotland, and made himself acquainted with the construction and performances of Symington's neglected steam-boat, Fulton returned to America, and successfully introduced steam-boats on the Hudson between New York and Albany. To Fulton is due the credit of coming to this country and carrying into practice, with the most beneficial results to mankind, a British combination neglected by the British nation. It is a singular, yet melancholy fact, that at the same time the two most remarkable inventions of any age,—practical steam-boats and practical locomotive engines,—were both lying for years as a "reproach" and a "byeword" on the highways of Great Britain,—Symington's steam-boat on the Forth and Clyde Canal, Trevitheck's locomotive engine in a ditch by the road side! Both the inventors died poor, neglected men. America had also her neglected Evans, and France her Cugnot. May we not therefore the more appreciate such men as Boulton, who rescued a Watt from such world-wide difficulties.?

Fulton's first steam-boat, the "Clermont," built in 1807, was 130 feet long, 16½ feet wide, 7 feet deep, and 160 tons burden, worked by one of Watt's double-acting engines, with a vertical cylinder two feet diameter and four feet stroke, connected to the paddle-wheels W W, Fig. No. 106, fifteen feet diameter and four feet broad, by the side levers and outside connecting rods 1, 2, and gearing S *b*. Each paddle-wheel was on a separate axle B, C, having on its inside end a crank 3, 4, for the connecting rod, and a toothed wheel, *a b*, to gear into another on the fly-wheel shaft

Fig. No. 106.



Fulton's Steam-Boat, 1807.

S. As there was only one engine, a large fly-wheel, F, worked in the centre of the boat between the ends of the paddle shafts, to continue the rotation past the dead points of the crank, as shown in the Fig. 106.

American river steam-boats are now celebrated for their size, superior accommodation, number, low fares, and speed, over those of any other nation. On the Hudson, for instance, where steam navigation for hire was first introduced, besides many smaller vessels averaging 200 feet in length, there are upwards of ten floating steam palaces averaging 310 feet length. Two of them are above 1000 tons burden, and many of them travel twenty miles an hour with safety, for explosions are all but unknown on this river. From New York to Albany, about 150 miles, the fare is only 2*s.* 2*d.* in these floating palaces. This is a higher velocity than our parliamentary trains, and at one-fifth the cost to travellers.

Bell, 1800—1812.—In 1800 Mr. Bell fitted a four-horse steam-engine in a small vessel, and sailed from the Clyde to the Thames at the rate, as stated, of seven miles per hour. The extraordinary appearance, it is said, led a sloop of war to give chase in the Bristol channel ; and on an Admiralty inspection in the Thames, considering the invention of no value, Nelson remarked, "Gentlemen, if you do not take advantage of this invention, you may rely on it other nations will." Even this mediation of England's great naval captain failed to secure Bell any better treatment than had been meted out to Savary.

The machinery was taken out and the boat sold. Another application in 1803 shared no better fate, and in 1812 Mr. Bell constructed the "Comet" steam-boat of 25 tons, worked by an engine of about three horse-power, which realized about five miles per hour on the Clyde. As soon as Mr. Bell had overcome popular prejudice and obtained passengers, powerful

companies started into existence, which deprived him of any reward for his meritorious exertion and heavy pecuniary sacrifices.

Stevens, 1804.—With a Watt's engine of only four-and-a-half inch cylinder and nine inches stroke, supplied with steam form a boiler consisting of eighty-one horizontal copper tubes, one inch diameter and two feet long, Stevens, of Hoboken, in America, propelled a steam-boat four miles an hour by a screw, on the principle of the smoke-jack vanes. The tubular boiler deserves notice from the number and position of the tubes, being similar to the modern locomotive boiler, excepting that the latter makes the tubes flues, whilst Stevens made them boilers, as was generally done by all common road steam-engines, with steam from 200lbs. to 300lbs. pressure per square inch.

Stevens also constructed one of his boilers six feet long, four feet wide, and two feet deep, with one-inch tubes, to give a heating surface of 400 square feet.

In 1815 Ralph Dodd had a fourteen-horse engine fitted into a seventy-five ton boat, and during a stormy voyage from the Clyde by Loch Ryan, Dublin, Milford, to London, of about 758 nautical miles, run in 122 hours, he clearly showed the power of steam to contend against dangers which would have destroyed sailing vessels.

In 1818 Mr. David Napier successfully prosecuted ocean steam navigation, and in 1822 the "James Watt" of 100 horse-power and 440 tons burden ran from Leith to London, realising a speed of ten miles an hour.

Since that time steam navigation has steadily progressed, and engines with their pistons connected directly to the crank, as in locomotives, without any side levers or beams, are now preferred. Of these direct-action engines the oscillating class are most compact, by also dispensing with the connect-

ing rod, as in Fig. No. 101, made by Penn & Sons, Greenwich.

It may be remarked that rotatory steam-engines introduced by Hero, employed by Branca and Matthesius, have engaged and still engage much attention. The goal aimed at is to obtain from the direct impulse of steam a rotatory motion as uniform as a water wheel, but its economical realization is a difficult problem.

A great variety of rotatory engines have been proposed by Maudsley, Clegg, Chapman, Witty, Ovens, Turner, Routledge, Moore, Congreve, Masterman, and many others of quite recent date, but with limited success.

Amongst the latest is one by Mr. Andrews, of the Great Western Railway locomotive department, combining both Hero's and Branca's plans in a modified form. One of them, about four-and-a-half feet diameter, with two jets only, was tried at Swindon, which was unfavourably reported of: and it is only fair to give the following good results, handed me by the patentee, as made on a roughly got up five-feet engine, with four jets, and tested by a seven-feet lever Prony's brake, loaded at its extremity :—

Exp. 1st,	Started quickly,			with 140lbs. load
,, 2nd,	Revolv.	84	per min.	with 409lbs. ,,
,, 3rd,	,,	280	,,	with 150lbs. ,,
,, 4th,	,,	3000	,,	without a load.

Steam from eighty to ninety pounds per square inch, was supplied through the hot water steam-pipe of a locomotive boiler standing on the rails at some distance off, and conveyed to the engine by a gas pipe. The inventor expresses great confidence in the result of a fair trial in practice.

The disc and eccentric piston engines are intermediate classes, where a rotatory motion is obtained from the circle

described by the piston-rod. Part of the machinery in the Exhibition of all Nations was worked by an eccentric piston rotatory engine, which receives and exhausts steam at two parts of the stroke like a reciprocatory engine, consequently requiring a fly-wheel to continue the motion over the dead points. Whilst genius and experience continue thus directed, they may succeed in solving the problem, but hitherto rotatory engines have failed to compete in economy of power with the expansive reciprocatory engine.

Steam has not attained its eminence without competition; for, besides hot air, gunpowder, gun-cotton, turpentine, alcohol, and explosive gases, have all been tried as sources of motive power, and still occasionally attract notice.

In 1791 R. Street dropped turpentine on hot iron, and exploded the vapour formed below a piston to produce motion.

In 1807 M. De Revaz moved a locomotive carriage by exploding a mixture of hydrogen and air in a cylinder by electricity.

In 1820 the Rev. M. Cecil discussed the comparative merits of steam and an explosive mixture of air and hydrogen, and proposed an engine to be worked by the explosion of air and hydrogen.

In 1823, 1824, Mr. S. Brown constructed a similar, but greatly improved explosive gas engine. Mr. Brunel tried a carbonic acid gas engine; and, modified, these plans have been revived again in America, with other alcoholic gas engines.

Electricity has also been tried somewhat extensively, and both in Great Britain and in America electro-locomotives have realized from six to ten miles per hour with a limited load.

In this fertile field for genius to revel in, it is as yet quite uncertain what treasures may be culled of the motive power class, although at present practically uninviting.

At the last Swindon Mechanics' Soirée were exhibited

several models of engines, both by steam and electricity. Amongst the latter was one by James Squires, driving a sectional model of one of the large broad-gauge engines, and another, producing rapid motion, by William Bickle. The latter had two electro-magnetic coils on each side of the centre of two levers, having broad parts immediately over these coils for attraction and repulsion alternately, and their other longer ends were connected to the fly-wheel axis, as in the steam-engine. By a self-acting cut-off valve, for the electric current at opposite angles at the same moment, a double-cylinder action is obtained, which in the small model spun round the fly-wheel with great rapidity.

Squires' plan was by placing the poles of a horse-shoe electro-magnet within the attractive distance of the arms of a fly-wheel, and by a self-acting cut-off produced rotation with considerable power, for the size of the model.*

Ericsson, 1829—1853.—Before closing this historical sketch, the exertions of this enterprising Swedish engineer to introduce hot air as a competitor with steam on the fair field of ocean navigation, require to be noticed, although any remarks now made are liable to be superseded by the results so anxiously looked for by an expectant world.

In England, Ericsson designed the novelty locomotive tried at Rainhill, in 1829; the rotatory-engine steam-boat, tried at Liverpool in 1832-3, with great velocity in the water, but excessive consumption of steam; the hot-air engine, tried in 1834 at Braithwaite and Co.'s, London, with success as a motive power, but failure from friction in the hot cylinder; and his screw-propeller steam-boat of 1837, tried by the Admiralty on the Thames, with much success in public opinion, yet con-

* These models were shown at the conversazione of James Rendel, Esq., President of the Institution of Civil Engineers. London: 1853.

demned by the Admiralty surveyor, and officially ignored at the time.

The American Captain Stockton, however, formed a different opinion; had a larger vessel built at Liverpool in 1838, and sent to America in 1839, where, as the "New Jersey," it plied on the Delaware with success, and screw-propellers are now generally preferred for many purposes.

Since that time Captain Ericsson has been chiefly in America, and has found in B. Kitching, Esq., of New York, a second Boulton, to aid him in testing hot-air power on a truly magnificent scale of operations.

The principle of caloric or hot-air power is heat, the same as in steam or hot-water. In the former air is expanded, and in the latter water is expanded to give out elastic power.

As we have before shown, air is estimated to expand $\frac{1}{480}$th of its bulk for each Fahrenheit's degree of heat added to it; and as its pressure is nearly in the ratio of its volume and space, it follows that by adding 480° of heat to the ordinary air, it would double its volume, or if confined, double its pressure. This would give a total pressure of two atmospheres, and, independent of a vacuum, leave one atmosphere 14·7lbs. per square inch of available power, which inventors seek to apply as a motive power instead of steam.

The difficulties hitherto defeating the success of hot-air power are, the high temperature of about 570° required in the working cylinder, volatilizing or carbonizing any known lubricant, and the excessive friction thereby occasioned.

Perkins experienced the same difficulty with his high-pressure steam, but then he would have at least 33 times the power of air of equal temperature, or upwards of 1000 lbs. per square inch.

The preceding pages have shown that hot-air engines are as old as steam-engines, and that in design they were not surpassed before Newcomen's time, nor yet surpassed by caloric

engines as regards heating the air in a separate vessel from the working cylinder. In engines, both rotatory and reciprocatory, Cardan, Branca, Amonton, Leupold, Hautefeuille, and others, have sought to produce an effective hot-air power, or, as in Wilkinson's and Houston's recent patents, by air and steam combined in the same boiler or cylinder.

The obvious safety from explosion, and the lightness of the whole engine, led Sir G. Cayley, in 1804, to propose a hot-air locomotive, which was tried in London, in 1807, before several scientific gentlemen, including the late Mr. Brunel and Mr. Gurney. About 1819-20, Mr. Greenwood had a hot-air engine made and tried at Manchester, with one forcing-in air-pump, and another exhausting air-pump, but the friction led to its disuse.

In 1834 Mr. Stirling had a reciprocatory hot-air engine made by his brother at Dundee, where it worked for several years with much economy of fuel, but, as in others, the friction was a serious drawback to its real utility.

This engine had a wire-gauze absorber of escaping heat, which it restored to the cold air entering through its meshes to the cylinder, and a similar gauze-chamber is an important feature in Ericsson's caloric engine. This gauze reservoir Mr. Stirling called a refrigerator, from its cooling the escaping air; but Captain Ericsson calls it a regenerator, from its heating the entering air.

So far as we can learn, Ericsson's engine is a modification of Sir G. Cayley's and Mr. Stirling's, with his own compact arrangement of the mechanism. We now describe it, to the best of our judgment, as follows :—

The hot-air cylinder, about fourteen feet diameter, has placed at some distance above it the air-supply cylinder, about eleven and a quarter feet diameter, and the open ends of both cylinders facing each other. In the top of the supply

cylinder there are two valves, of which one part opens inwards, to admit air, and another part opens outwards, by which to force the air out by the pipe into the airometer. In the bottom is placed a number of thicknesses of wire-gauze, having a surface of many square feet, through which the air passes both to and from the working-cylinder. The slide-valve alternately opens the ports, to admit air to the cylinder, and from it to the atmosphere. The lower part of the working piston is extended downwards, but not fitting the cylinder, that its expansion may not injuriously affect it, whilst it guards the air-tight part of the piston from the direct action of the hot air. The pistons are connected together, which preserves their parallelism, and a bell-crank lever, connected by a link or slot to the main piston-rod, gives motion to the machinery. As the cylinders are only single-acting, it requires four cylinders to give the rotatory power of two double-acting steam cylinders, and they are placed two and two on each side of the paddle-shaft, in lines parallel with the line of the vessel. The connection with the crank-shaft is so arranged, that each pair of acting cylinders work at right angles to each other, as in the double-crank engines.

The action is regulated by the slide-valve, admitting air to the cylinder where it is exposed to the fire, and as it expands by the heat, both pistons are raised simultaneously about six feet high. The large piston gives motion to the machinery, and the small one forces the air to replace that withdrawn from below, and thus balance the supply and demand of air. As the pistons are in an equilibrium of atmospheric pressure on both sides during the downward stroke, their own gravity, aided by the full-power action of the other cylinder, carries them to the bottom ready for another upward stroke again.

At this point the wire-gauze recipient or heat-ometer comes into action, by absorbing heat from the escaping hot air, which

is again re-absorbed from the wire-gauze by the cold air passing through it to the cylinder. Its action is precisely similar to that of the respirator worn by invalids or others in cold weather; for in both the human and mechanical arrangement, heat is absorbed by the wire-gauze from the expelled air, and returned to the air which enters through it to the lungs or to the cylinder.

In Ericsson's engine it is stated, that the heat so "caught" in escaping and returned to the cylinder is about 460° out of 510° of added heat to that in ordinary air, and requiring from the fire only about from 50° to 70° to replace that lost by radiation or other causes, and the generation and consumption of caloric or heat is thus adjusted.

In this way the actual consumption of heat is economised to about 25 per cent. of that required for steam; but the amount of friction in passing through the gauze is not as yet publicly known in England, and is highly estimated.

The name of regenerator has been objected to, as implying a creator of power, whilst it is only a recipient of heat, which would otherwise be lost, and perhaps heat-ometer would convey a clearer idea of this important "picker-up" of $\frac{14}{19}$ths of the escaping heat for further duty. If a similar proportion of the 1180° of heat in 30 lbs. steam could be returned to the boiler, the economy of fuel would be very decided, since at most only about $\frac{1}{6}$th of it can be so retained in water heated, by waste or exhausted steam, to the boiling point.

With a practical solution in progress, so much more satisfactory than any theoretical one, it will be unnecessary to discuss the relative expansion of steam or flame and air by heat, since the power of the latter, if safer, is much more confined than that of the former.

The pressure on the supply piston acts against the working piston, at a mean force from zero up to full pressure, about half stroke. In the recent trials a working pressure of 12 lbs.

was said to be realized, and taking 10 lbs. as the full mean pressure on the supply piston, an estimate of the power may be thus arrived at:

	sq. in.		lbs.		lbs.
Area of working cylinder	22167	×	12	=	266004
Area of supply cylinder	14426	×	10	=	144260
Which leaves an available power				=	121744

to move machinery and overcome the friction of the engine, or about equal to 24 lbs. effective steam on an 80-inch piston. The power therefore of Ericsson's two pairs of cylinders, with 6 feet stroke, would be about the same as two 80-inch double-acting cylinders with a similar stroke, and 24 lbs. high-pressure steam, or 12 lbs. steam in a condensing engine, whose vacuum supplies the other 12 lbs. Double-acting cylinders would however be as valuable to caloric as to steam-engines, which were also single-acting till Watt's time.

The power given out by hot air is, however, variously regarded by the most experienced engineers, who doubt its success, which time will soon solve; but that power is obtained from hot air is quite evident from the example given, less the additional friction of four pistons instead of two in the steam-engine, leaving the air-pumps as equivalent to water-pumps and parallel motion.

From working models of other hot-air engines there appears to be no difficulty in making any number of strokes per minute up to at least 150 or more, but past experience points to friction as the chief obstacle to hot-air engines. Against the disadvantages of friction, unequal expansion of the cylinder, oxydation or leakage, to be overcome by skill and ingenuity, are to be placed the advantages of safety from explosions, economy of fuel and of space,—all considerations of importance in navigation,—and other mechanical operations.

The practical results, therefore, of Ericsson's experiments will be deeply interesting in any point of view; but it will be most satisfactory to learn that he triumphs over those mechanical difficulties which have hitherto retarded the progress of hot-air engines.

Portable Farm-engines.—In the mine, in the factory, on the ocean, and on the rail, steam had produced results of vast importance before its aid was valued by agriculturists. Indeed, its first essay to do the work of horses was resolutely opposed as injurious to their interests; but other opinions now prevail, and steam assists the producers of the staples of food and clothing, as it has long done the manufacturers of metallic, textile, or other products of science and art.

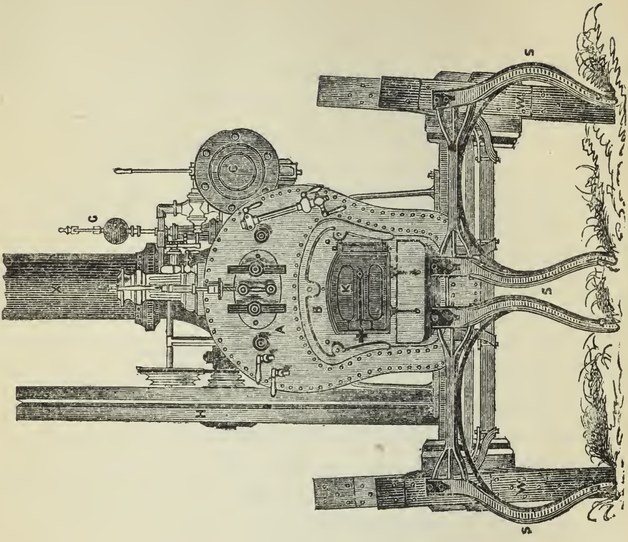
Under the auspices of the Royal Agricultural Society, the farm-engine nearly rivals in economy the factory-engine, although defects, which will be noticed, exist in some of these engines, which can be easily removed.

As a fair example, Messrs. Garrett and Sons' engine was considered by Mr. Carr, of Belper (the Exhibition Jury Reporter of 1851), "the most portable, for its power, of any exhibited" in Hyde Park, which portability is obtained by chiefly using wrought iron in the construction.

Fig. 108 is a fire-box end view, and fig. 109 a smoke-box end view, of this engine. To the fire-box B is fitted the exposed cylinder C, and the parallel motion D is fitted to the boiler A. The fly-wheel H drives the farm machinery, and is connected to the piston by the rod F, whilst the eccentric rod E works the slide-valve. I the water tank, G the governor, H the fire-door, S the shafts, V the safety-valve, W the supporting wheels. The gauges, steam-pipe, and regulator handle are seen on the end views.

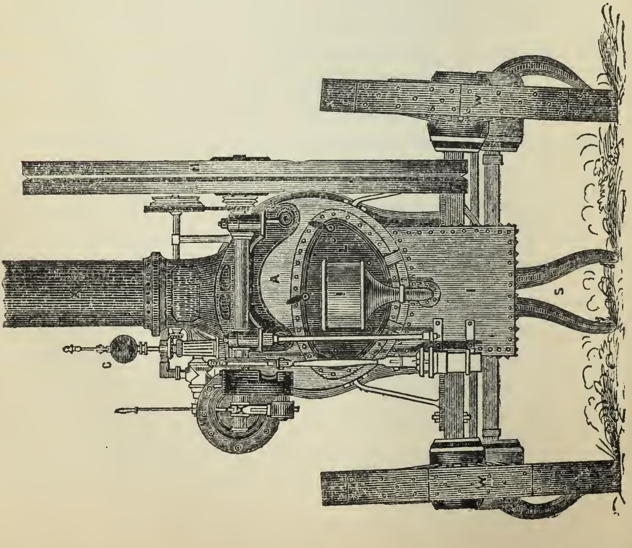
Amongst the farm-engines in the Crystal Palace of 1851 were several of good workmanship, but many of them had exposed cylinders, as if Watt and others had never gained

FIG. No. 108.



Fire-box End.

FIG. No. 109.



Smoke-box End.

largely by protecting the cylinders from external cold. Practically, the exposed cylinder is a stove as well as a source of power. Steam of 35 lbs. pressure per square inch above the atmosphere, or 50 lbs. total pressure, has a heat of 283°. Now, if a cylinder, or steam pipe, filled with such steam, is surrounded by an atmosphere of 65°, the heat of the steam is rapidly transmitted to the air, and the hands may be warmed at such a cylinder as they might be at any ordinary stove. There is, then, time, heat, and power lost; for it is well known in railway practice that the useful effect decreases with the increase of water in the cylinders, whether there be condensation from ill-protected cylinders or by priming.

The following description of the Exhibition engines, and the dynamic results of these trials, are condensed from the Jury Report of 1851.

General Description of the Engines tried.

Hornsby and Sons.—A horizontal cylinder, fitted centrally in the steam-dome over the fire-box; the boiler covered with dry hair, felt, and wood, and the feed water heated in the smoke-box.

Tuxford and Sons.—No. 1. A vertical cylinder, and the machinery neatly fitted in a case at the end of the boiler, with folding doors to lock up all when required. Their No. 2 engine was similarly constructed, but with an oscillating cylinder.

Clayton and Co.—Neatly arranged, good working engine, with an external horizontal cylinder; now (1853) inclosed in steam.

Garrett and Sons.—Light, strong, portable engines, with an external horizontal cylinder.

Barrett and Co.—External horizontal cylinder, large boiler, and expansive link-valve motion.

Cabron.—Strong heavy engine, with indifferently arranged machinery.

Butlin.—Workmanship moderate, and machinery of simple design.

Burrell.—Machinery simply arranged, and fair workmanship.

Hensman and Son.—The workmanship moderately good, but the boiler too small.

Roe and Co.—Too much cast iron used, with inferior workmanship and arrangements.

PRACTICAL RESULTS OF THE DYNAMIC TRIALS.

Maker.	Horse Power.	Time of getting up Steam.	Coals used in getting up Steam.	Coals used per H. P. per Hour.	Coals used per Hour of Hornsby's Engine.	Coals used per Hour Difference.
	No.	Men.	lbs.	lbs.	Per cent.	Per cent.
Hornsby & Son.	6	49	35·23	6·73	100·0	
Tuxford & Son.	6	53	56·68	7·46	110·8	10·8
Clayton & Co.	6	32	35·40	8·63	128·2	18·2
Garrett & Sons.	5	42	26·50	8·65	128·5	18·5
Barrett & Co.	4·5	26	25·56	9·20	136·7	36·7
Tuxford & Son.	4	41·5	35·60	10·85	161·2	61·2
Cabron . . .	9	44	52·00	12·48	185·4	85·4
Burrell . . .	6	28	35·00	13·10	194·6	94·6
Butlin . . .	4·5	50	42·00	14·71	218·4	118·5
Hensman & Son	4	33	29·00	18·75	278·6	178·6
Roe & Co. . .	4	83	75·20	25·8	383·3	283·3

These results were taken by a Prony's brake, on the plan of the Royal Agricultural Society; but it is respectfully suggested that, in addition to the final results, the water evaporated or carried out of the boiler should also be given. The processes of generating and employing steam are, as has been shown, quite distinct, and it would promote the objects of the society to be able to state in their reports whether the discrepancies between engines arose from the boiler or machinery, by simply comparing the evaporative economy with the final economy; for steam once generated, and afterwards condensed before it has left the cylinder, is a great but unseen absorber of steam power.*

The hourly consumption of fuel by these engines follows generally the more or less carefully protected heat, after it is the life of steam.

Thus, Hornsby's well-clad boiler, well-protected cylinder, and hot feed-water, is 10 per cent. more economical than Tuxford's, with the next best protected cylinder; 28 per cent.

* With their steam-surrounded cylinder at Gloucester, in 1853, the coals were only 4·3 lb. per horse-power, which gained the first prize.

more economical than Garrett's or Clayton's, with exposed cylinders; and 36 per cent. superior to Barrett's engine; showing the advantages of well-protected boilers and cylinders, as proved by Clayton & Co., at Gloucester, in 1853.

Steam-Ploughing.—Amongst the first public trials of steam-ploughing was that made by Mr. Heathcote, M.P., on Lochar Moss, at the Scottish Highland Agricultural Society's Dumfries Meeting in 1836; and of late years Lord Willoughby d'Eresby has most commendably persevered to reduce steam ploughing to practice. His engines and implements both admit of improvement, but experience will contribute her counsels and ingraft them on the original plan as on other new fields of enterprise. The present system is to lay down a light portable road at each end of a field, with a portable engine on each road; a chain drum fitted to each engine is worked by the steam, and this chain is connected to the plough, or other instrument, mounted on wheels, and adapted to the soil or duty required. The ploughman regulates the depth of the furrow by levers, and the ploughs are alternately drawn to and from each engine by reversing the motion of the chain off or on the drum. As each set of furrows is completed the engine is moved that distance along the end road, so that the chain may again act in a line with the traction. The comparative economy is stated to be in favour of steam.

As practical examples of this system, the California engine and a plough with four shares and four subsoil prongs were shown at the Exhibition, (No. 195, Class 9,) by Lord Willoughby, but less width of soil acted on at once and greater speed of travelling is now adopted, as lately tested by Prince Albert on his farm at Windsor.

The difficulty of the power moving with the implement is thus obviated, and the question reduced to one of tractive power and portability from field to field. With light engines, capable of using steam of 120 lbs. to 150 lbs. pressure per square inch, as in locomotives, and well-adapted implements to

localities, or soils, or duties, Lord Willoughby's system appears capable of extension to many districts, and the engines which now stand idle part of the season may usefully till the land.

A model of a steam plough of a different class was shown by Mr. Usher, of Edinburgh, (No. 123 A, Class 9,) with revolving blades behind the locomotive engine, mounted on wheels. It therefore breaks up or comminutes the soil.

The number of the blades are regulated according to circumstances, and some practical trials of this class of steam ploughs, about six tons weight, have been favourably mentioned in the public journals. In Usher's design the power moves with the implement, but in Lord Willoughby's system the power is stationary during the time of action.

Having shown the practicability of steam ploughing, it is said that Lord Willoughby intends to close these experiments, and try steam locomotion on common roads.

The railway locomotive was long regarded as inferior in economy to horses, until, in 1828, Hackworth's Royal George clearly proved the contrary. Yet even Mr. R. Stephenson's experiments on this engine were held, in 1829, to be exceptional by Messrs. Walker and Rastrick, as Lord Willoughby's appear to be generally regarded at present; but, as in the railway case so in the agricultural one, time may develop its progress, and a stud of steam horses form a necessary portion of farm stock for field or other work.

In these few pages we have sought to compress an illustrated chronological chart of the principal chiefs, and progress of the steam family, for upwards of 2000 years. Distinguished however as it has become, its founder is unknown in the annals of heraldry. Of its two branches we have just seen how far the rotatory has been left in the rear by the reciprocatory branch, which has performed all the mighty deeds of modern times, by the combined forces of caloric, or heat and water. We may form some faint idea of the anxious hope and fear of each succeeding genius before his conceptions were clothed in mental or material form—the parental grief or joy as each

child expired in infancy or arrived at manhood and fame. The scientific knowledge of such men as Desaguliers, Emerson, Smeaton, Black, Robertson and others, were all brought to bear on the progress of the reciprocatory steam-engine. It also embraces the material leading inventions of the loaded safety-valve, piston and cylinder of the ancients; the tubular boiler and steelyard safety-valve of Papin, a French physician; the condensation vacuum and gauge-cocks of Savary, an English miner; of the beam, boiler-pump, injection-pump, and vacuum below the piston of Newcomen, an English blacksmith; the hand-gear of Potter, an English peasant boy; the fly-wheel of Fitzgerald, an Irish professor; the condenser air-pump, double action, parallel motion and governor of Watt, a Scottish mechanic; the crank motion of Pickard, an English mechanic; the metallic piston of Cartwright, an English dissenting clergyman; the oscillatory cylinder, eccentric motion and slide-valve of Murdock, a Scottish mechanic; and the double cylinder of Hornblower, an English mechanic. From these inventors' inventions, modern engineers select at pleasure to construct an efficient engine for the duty to be done.

The first modern engine was Watt's, a Scottish mechanic; the first modern locomotive engine was Trevitheck's, an English mechanic; and the first modern steam-boat was Symington's a Scottish mechanic. The first regular river steam-boat was Fulton's, an American mechanic; the first ocean steam voyage was made by Bell, a Scottish engineer. The most economical engines of the present day are constructed by Cornish mechanics; and the first locomotive was Cugnot's, a French engineer.

The amount of intellectual toil concentrated in a modern reciprocatory engine will therefore be obvious, as also that the principal inventions and combinations are those of working mechanics, who have nearly all died in poverty and distress.

We have now arrived at the locomotive epoch, and under the impression that the preceding outline of the elements

of steam, of fuel, and of combustion, with their first-fruits in the garden of industry, will render the path more pleasingly instructive, we now propose to trace out the progress of railway steam locomotion to its present importance and latest forms of engines.

Those who desire a further knowledge of stationary and marine engines, illustrated by elaborate engravings, are referred to Tredgold's third edition of the "Steam Engine," "Pole's Treatise on the Cornish Engine," "Alban's Treatise on High Pressure Engines," "Woodcroft's Treatise on Marine Engines," and "Murray's Rudimentary Marine Engine."

Since 1822, the locomotive power of the reciprocatory steam-engine forms one of the most remarkable events of the age. For ocean locomotion, the varieties of the stationary engine are used, but with their cylinders shortened and of larger diameter to suit the hold of the ships. The beam is replaced by one on each side of the cylinder, connected together by a cross-piece, into which the piston rod is fitted. Oscillating engines are also employed in steam-boats, and require less space than beam engines. Boilers are made of such forms as to suit the vessels, but even on land, where space is no object, the forms of boilers have varied and still vary much. Watt's waggon class is losing ground from its weak form. Woolfe's, as improved by Galloway, and Evans', as adopted by Trevitheck and the Cornish engineers, maintain a high reputation. Alban's improved tubular boiler enjoys a good name in Germany, and the locomotive tubular-flued boiler is also used for fixed engines. The railway locomotive engine is self-contained, and takes a form of its own adapted to its special duties, which will be explained and illustrated in the next volume.

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